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**A TEST PROCEDURE FOR SHORT-LIFE RATING
OF COMPOSITION RESISTORS**

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BATTELLE MEMORIAL INSTITUTE

JULY 1953

WRIGHT AIR DEVELOPMENT CENTER

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OF COMPOSITION RESISTORS**

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Battelle Memorial Institute***

July 1953

***Electronic Components Laboratory
Contract No. AF 33(038)-1229
RDO No. R-112-140, SR-6d3***

**Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio**

FOREWORD

This report was prepared by Battelle Memorial Institute, 505 King Ave., Columbus, Ohio, on Supplemental Agreement No. 5(S-51-1794) to Contract No. AF 33(038)-1229. Work at Battelle Memorial Institute was initiated as a project of the United States Air Force, and was completed under the research and development contract identified by RDO R-112-140 SR-6d3. It was administered under the direction of Mr. Y. Jacobs, Mr. D. C. Bedwell, and Mr. C. Burneka of the Electronic Components Laboratory, Mr. Bedwell acting as project engineer. This is the final report on that phase of the contract dealing with life rating of electronic components.

Included among those who contributed to this study at Battelle Memorial Institute are D. B. J. Bridges, W. T. Sackett, Jr., J. H. Graham, E. A. Boyd, R. L. Davis, R. E. Martin, J. D. Roehm, R. L. Merrill, A. P. Jerencsik, and R. C. McMaster.

ABSTRACT

A short-life-rating procedure is given for composition resistors operated abnormally. Conditions of abnormal operation considered are high ambient temperature, altitude, load, humidity, and vibration. Details of equipment, methods of measurement, and mounting of samples are described.

The rating procedure utilizes sequential sampling, preconditioning of resistors, and statistical treatment of the data. Theoretical and experimental considerations leading to the procedure are given. The applicability of the rating procedure to other electronic components is indicated.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

FOR THE COMMANDER

RICHARD S. CARTER
Colonel, USAF
Chief, Electronic Components Laboratories

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INTRODUCTION

The research described in this report is a contribution of the staff of the Electronic Component Information Center (ECIC). The ECIC is a machine-system center for storing and searching engineering data on electronic components.

There are two distinct requirements for a useful ECIC: the machines and the data. The machine system must handle⁽¹⁾ efficiently any form⁽²⁾ of engineering data needed for application of electronic components. A workable machine system has been reported previously⁽³⁾.

ECIC is, of course, no better than the data it contains. Many of the needed engineering data already exist. However, in order that the data be useful, care must be taken to insure that they be collected in such a way that all test values are comparable. Standardization of electronic-component test methods is in progress at various places, including Battelle.

One area for which very few useful data or standard test methods exist is in the use and rerating of electronic components operated under abnormal conditions. In particular, some airborne equipment must operate under extreme conditions of temperature, altitude, and/or vibration.

This report is concerned with the development of standard test procedures to rate components for operation under these extreme conditions. Data obtained from the tests would be entered in ECIC eventually and be made available to engineers, designers, and users of electronic equipment. It is emphasized that this work was undertaken, not to supply the data, but to supply standard methods for obtaining data.

The over-all purpose of this research has been to develop methods for rating electronic components which operate under the abnormal conditions which occur in some airborne applications. The development of rating procedures for all electronic components operated under all conditions of interest is a rather formidable task. As a first step toward this goal, work has been concentrated largely on the short-life characteristics of a relatively simple component: the composition resistor.

The basic approach in this research consisted of the following steps:

- (1) Outline the most logical procedure for rating life based on experience and consultation with experienced leaders in the field.

(1) Handle means take in, store, search, and send out.

(2) Examples of "forms" of data are tables, curves, equations, and nomograms.

(3) "A Machine System for Accepting, Storing, and Searching Engineering Data on Electronic Components", Phase Report No. 1, June 28, 1952, from Battelle Memorial Institute to Wright-Patterson Air Force Base.

- (2) Evaluate the procedure by performing life tests to determine whether meaningful data are obtained.
- (3) Revise the procedure as needed to obtain data which are more useful.

Progress using this approach on resistors has been reported previously.^(1, 2) Similar work has been reported for capacitors.⁽³⁾ This final report describes the result of the basic approach on composition resistors, with the following exception: No laboratory evaluation has been done since September, 1952. The Sponsor requested that the second step of the basic approach be omitted for expediency. Development and study on the procedure continued to about May 1, 1953, but verification and evaluations by actual tests were stopped in September, 1952.

The body of this report is divided into five major sections:

- (1) Basic Considerations in the Development of Life-Rating Procedures. This section presents a discussion of several problems (such as defining "life" and obtaining representative samples of components) which are common to some degree to all electronic components. Extension of certain procedures developed for composition resistors to other components is discussed.
- (2) A Brief Description of the Life-Rating Procedure for Composition Resistors. The purpose of this section is to show briefly what assumptions and compromises have been made in choosing the tests given in the rating procedure. The form of the data which the tests will yield is indicated, together with an example of how the data might be used.
- (3) Detailed Short-Life-Rating Procedure for Composition Resistors. The detailed test procedure is given. Included are the details of equipment, sample-mounting methods, and measurements necessary for performing the tests.

-
- (1) Thirteenth Interim Engineering Report, "A Study of the Prediction of Composition-Resistor Life", September 30, 1951, from Battelle Memorial Institute to WPAFB.
 - (2) Supplement to the Thirteenth Interim Engineering Report, "A Study of the Prediction of Predried Composition-Resistor Life", February 29, 1952, from Battelle Memorial Institute to WPAFB.
 - (3) Fourteenth Interim Engineering Report, "A Study of the Behavior of Capacitor Characteristics at Elevated Temperatures", October 30, 1952, from Battelle Memorial Institute to WPAFB.

- (4) Experimental Results. This section contains previously unreported experimental results which have helped lead to the rating procedure. The detailed conclusions concerning each type of laboratory study are given in subsections which follow the description of the experimental results.
- (5) Concluding Remarks.

BASIC CONSIDERATIONS IN THE DEVELOPMENT OF LIFE-RATING PROCEDURES

Objectives and Problems

The long-range objective of the work described in this report has been the establishment of a set of procedures for predetermining the (short-term) life of electronic components operated under any conditions of ambient temperature, load, altitude, humidity, and vibration. In the process of study and development on this problem, and in the evolution of the procedure presented here for composition resistors, many problems were uncovered. Ideas and guides for solving or circumventing these problems were conceived; many of these guides or methods of attack are general, i.e., they apply to many electronic components. This section on "basic considerations" discusses the more important of these problems and closes with suggestions and general guides for the extension of these procedures to electronic components other than fixed composition resistors.

The major problems encountered in the establishment of these short-term-life procedures for composition resistors are:

- (1) Defining life.
- (2) The many combinations of the test-condition variables.
- (3) The wide variability in the lifetimes.
- (4) The difficulty in obtaining truly representative test samples.
- (5) The large effect of storage history and conditioning methods on life.

Definition of Life

One of the first problems that must be considered in life testing any component is to arrive at a reasonable definition for life. For a fixed resistor, the property of major interest is the resistance value. A secondary property that may be of importance in some applications is the noise generated by the resistor. Almost all other components have many more characteristics that must be considered. For example, a capacitor has the properties of capacitance, dissipation factor, leakage resistance, absorption, and break-down strength, any one or all of which may be used to set up criteria for life.

One of the most frequently heard suggestions for defining life is that "when a component exceeds its tolerances in any property, the life is ended". Although any definition selected will be arbitrary to some degree, such a definition is quite illogical. Composition resistors are sold in ± 5 , ± 10 , and ± 20 per cent tolerances. However, there is no difference other than resistance tolerance among these three classes of resistors; in fact, the 5 and 10 per cent resistors usually are obtained by automatic sorting, leaving a hole in the center of the distribution curve of the 20 per cent resistors. Thus, in the deterioration process, some resistors would have only a few per cent change to exceed tolerance, but others could change by 20 per cent before exceeding tolerance. This would add several orders of magnitude to the variability in lives and thus detract from the value of the life ratings.

General considerations to follow in choosing a life definition are:

- (1) The definition should be related to the deterioration process; reversible changes, such as those due to temperature characteristic, should not enter into the life definition.
- (2) The most critical property (the one which changes most with least operating stress) should figure in the definition.
- (3) Other things being equal, relative quantities, such as percentage change in critical characteristics, should be chosen so as to give the least variable lifetimes, as well as "reasonable" life values.

Figure 1 portrays the typical behavior, under temperature stress, of a resistor manufactured by "A" company. The surface temperature of the resistor (following insertion of the resistor in an oven held at T degrees) is shown in the upper curve. The resistance is shown in the lower curve as a function of time.

The portion of the lower curve from a to b is reversible, and this should not enter into the life definition. A satisfactory definition would be

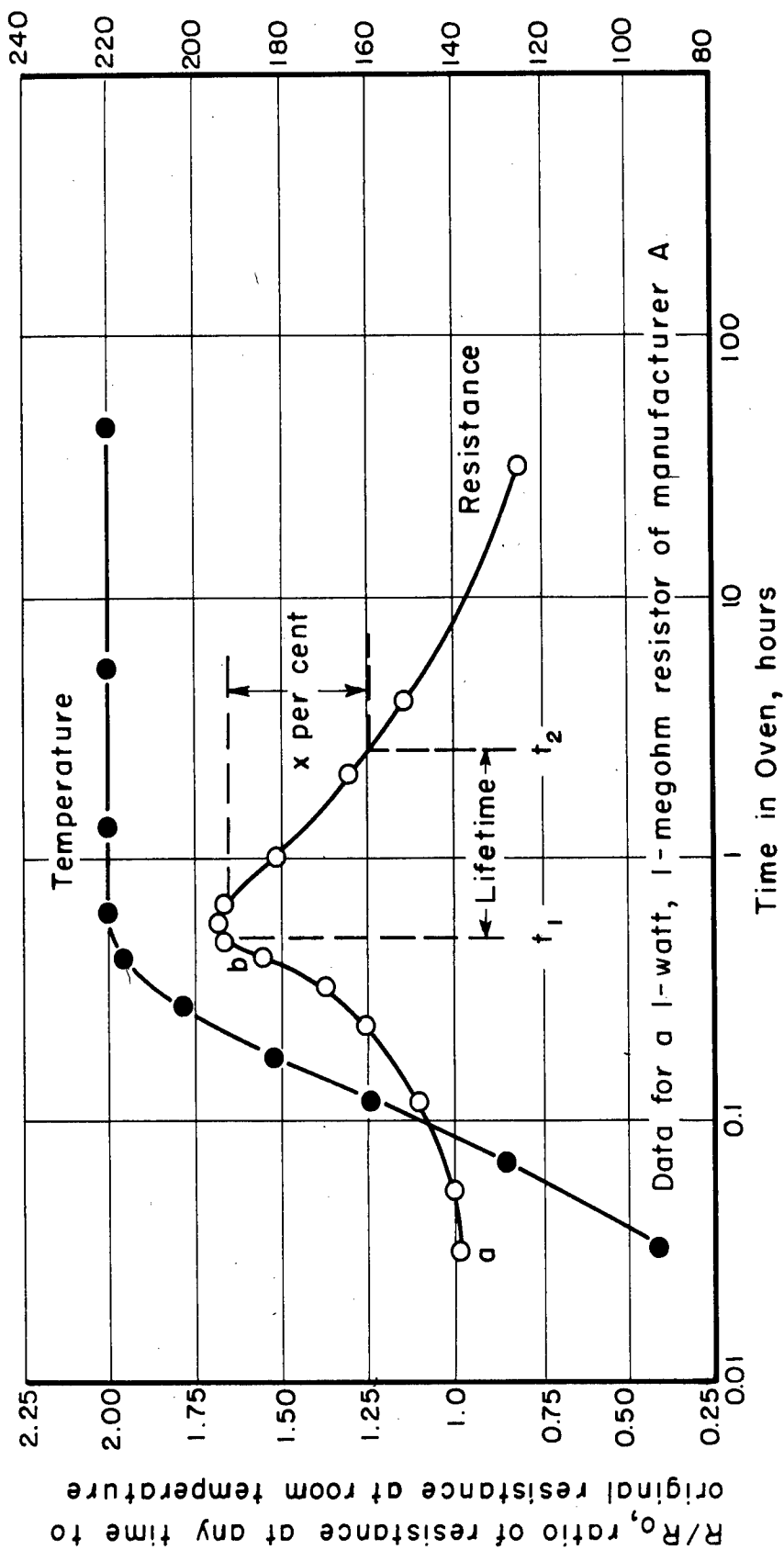


FIGURE 1. RESISTANCE AND TEMPERATURE AS FUNCTIONS OF TIME FOR "A"
RESISTOR BAKED AT 220 C

A-7114

the time ($t_2 - t_1$) required for an x per cent change in resistance from the initial value after temperature equilibrium is reached at b. In many cases, the designer might not be able to tolerate the magnitude of the change in resistance from a to b in his application. However, this type of decision is independent of the "life" of a resistor and may be determined in a straightforward manner, without life testing. Typical data of this type are shown in Figure 26, page 73.

In the procedure which follows, we have arbitrarily chosen 5 per cent change as the criterion for life of a composition resistor. Some of our experimental work indicates that a lower value, near 1 to 3 per cent, would give less variable life data. The data are not conclusive, however, and a low per cent change requires accurate resistance measurements to be made. It is almost certain that lower percentage values will be in order for carbon-film and wire-wound resistors.

Variables Influencing Life

Perhaps the most difficult problem which confronts the ECIC planners is the multitude of variables which influence the life of electronic components. For composition resistors, life has been shown to depend on the manufacturer, resistance value⁽¹⁾, and power rating. Add to this the ambient temperature, load, altitude, humidity, vibration, and storage history. If we postulate life tests over only a reasonable combination of the variables, the resultant over-all test program becomes immense. In spite of this, the test procedure given here appears reasonable and requires testing of only about 1500 resistors of a given size, type, manufacturer, and resistance value. We believe that any approach which eliminates a large amount of testing by supplying conservative (rather than "actual") life data is preferable if the loss of information is not too great.

Almost all the life testing prescribed in the detailed procedure (third major section of this report) is carried out under temperature stress alone. Curves of life as a function of temperature at no load are obtained and provide the basic life information. Then, by a series of "nonlife" or "load versus altitude" tests, surface temperature is obtained for the resistor as a function of load and altitude. A few load-life tests are then made under the most severe conditions likely, and a temperature factor of safety to be applied to the surface-temperature data is obtained by comparing the no-load temperatures required to produce the same lifetimes with the measured surface temperatures. To be conservative, the temperature factor of

- (1) Extensive testing would be needed to prove that life values obtained on the higher resistance values of a given type would be conservative for other resistors of that group, even though this seems a reasonable hypothesis. Such time-saving assumptions can be made, if at all, only on the basis of a wide background of test results.

safety is obtained under load and altitude conditions which are very severe from the viewpoint of producing maximum temperature rise in the resistor.

Humidity and vibration are considered in this procedure only to the extent of determining whether the lives are susceptible or not to these variables. If it later develops that these variables greatly influence the life of most resistors, it is suggested that severe vibration and/or humidity stress levels be selected and applied throughout the no-load life tests; the results obtained should then be conservative for almost any other values of humidity and vibration.

Starting-point information for all the life testing is obtained by running a one-hour no-load temperature-stress step test.⁽¹⁾ Next, high-temperature short-term lives are determined, and then the more expensive long-term tests are conducted. This sequence leads to efficient use of the knowledge gained at the shorter lifetimes.

A further viewpoint in developing the procedure has been that tests should be designed with the applications in mind. Since few applications would call for continuous operation of resistors beyond eight hours, all testing for longer lifetimes is set up on a cycled basis. A basic stress cycle of 2 hours on, 1/2 hour off is adopted here. Any choice is necessarily arbitrary. Further, the off period is not critical and, with proper precautions, can be stretched to avoid round-the-clock testing.

Variability of Life

The problem of variability in life data has no easy solution. It is this problem which makes statistical methods of testing a "must" in any procedure for obtaining life ratings. This point is discussed in the article referred to in Footnote 1, page 7, which points up to the inefficiency of attempting to extend such "go, no-go" life tests as described in JAN-R-11.

Our early measurements on short-term lives have indicated a log-normal distribution of life values⁽²⁾ at any given temperature; hence, the procedure calls for logarithmic transformation of life data before computing mean-life and confidence limits. This conclusion is only a tentative one and should be re-examined as life testing progresses.

(1) Jerencsik, A. P., and Sackett, W. T., Jr., "The Stress-Step Method of Obtaining Short-Term Life Ratings on Electronic Components", Proceedings of the National Electronics Conference, 8, 267 (1952).

(2) There are two distinct types of component failure. One type is characterized by a sudden or catastrophic change; the other, by a relatively slow deterioration of quality. "Life" as used throughout this report refers to components' failing slowly.

Representative Sampling

Destruction of the samples life tested also makes statistical methods of testing imperative. Further, the samples chosen must be representative of the manufacturer's production in order for results to be meaningful. The question which immediately arises is that of how representative samples may be obtained. Manufacturers of resistors could offer no easy answers when consulted on this problem.

The major difficulty here is that the short-term, high-temperature life of resistors is not controlled by the manufacturer. Hence, there is no assurance that batch changes will not produce radically different short-term-life characteristics. The only way so far envisaged to overcome this problem is to sample at successive intervals of time and to check continually at least one very short-term life (such as one hour) and one relatively long-term life (such as near fifty hours) on the successive samples. (The reason for the two tests is the probability that different mechanisms of failure are operative at the higher and lower temperatures.) Regular techniques of calculation based on quality-control procedures would then allow assignment of minimum values for the characteristics. This testing at intervals would have to continue unless the manufacturer were willing to bring these characteristics under control.

Storage History and the Conditioning Problem

In assigning life ratings, it would be most desirable to avoid the problems of conditioning resistors entirely. The obvious argument is that any ratings assigned should apply to all resistors, regardless of their past history, not merely to resistors which are kept "bone-dry". This argument presents several difficulties. The primary difficulty is that the moisture content radically influences the short-term-life and temperature characteristics and the variability of these quantities. Further, high moisture content makes the resistor's short-term life extremely dependent on slight variations in the testing procedure. For example, the life of resistors with high moisture content becomes very dependent on the rate of rise to the initial temperatures.

One problem here is due to the different constructions of various composition resistors. Some manufacturers use a wax coating to protect the resistors from moisture effects; some do not. As long as this coating keeps out the moisture, the resistor needs no conditioning. However, once exposed to temperatures high enough to disturb the coating, the resistors become susceptible to humidity and moisture effects.

In general, much longer lives at high temperatures are obtained on dry resistors than on moist ones. A life rating obtained without specifying the moisture conditions of the resistors would be of little value.

Let us consider a possible example. Suppose new, wax-coated, resistors well dried before coating were tested without conditioning and gave a life rating of 10 hours at full load and 200 C ambient temperature. Then suppose that a missile designer decided these resistors were good enough for his applications. Later, several hundred missiles were manufactured, given final ground checks, and then stored against the day of need. Now, assume that the ground-operating checks produced temperatures sufficiently high to damage the wax coatings of the resistors. Subsequently, storage allowed the resistors to absorb a fair amount of moisture. With this absorbed moisture, the average life at full load and 200 C was on the order of one-half hour. Hence, when fired, a high proportion of the missiles failed to operate correctly.

This hypothetical (but possible) illustration shows the need for caution in the establishment of procedures and life ratings for high-temperature use. The conditioning problem must be faced.

It is recommended here that temperature characteristics and life ratings be obtained on both dry resistors and moist resistors. Dry resistors will be obtained by conditioning resistor samples at 105 ± 5 C for 100 hours, then storing in a dessicator until testing. Moist resistors will be obtained by first subjecting them for one hour to the highest temperature at which they are likely to be used to stress whatever coatings may be present, then subjecting them to 50 C at 95 to 100 per cent relative humidity for at least 250 hours and from then until the tests begin. Life ratings will then specify the moisture content (as "dry" or "moist") of the resistors to which they pertain. It will also be necessary to obtain check measurements on resistors in the "as-received" state, which will be one of indeterminate moisture content, in order to assure that neither of these procedures improves the resistor quality (for example, by further curing of partially cured resins used in the composition).

Guides and Suggestions for Extension of the Short-Life-Rating Procedure to Other Components

Carbon-Film and Wire-Wound Resistors

It is believed that these procedures can be extended directly to carbon-film and wire-wound resistors. However, it will undoubtedly be advisable

to change the percentage change of resistance in the life definition to 1 per cent for carbon-film resistors and 0.5 per cent for wire-wound resistors. To do this, it will be necessary to increase resistance-measurement accuracy requirements to ± 0.05 per cent.

Variable Resistors

The extension of the procedures described to variable resistors, potentiometers, volume controls, etc., should be possible by prescribing that the no-load - temperature life tests be performed with a steady rate of rotation (or alternation) of the wiper blade. This rate should exceed likely service values. Contact noise becomes an additional property which must be studied, and perhaps used in the life definition.

Capacitors

The problem of establishing short-time-life ratings on capacitors is indeed a severe one, as discussed in the Fourteenth Interim Engineering Report from Battelle to WPAFB, dated October 30, 1952. Much further work must be done, preferably of a fundamental-study nature, since the dielectric problem is the key to the life-rating problem on almost all other components.

Transformers

It is believed that electronic power transformers can be handled by procedures similar to those for resistors, with the complication that the dielectric properties of the insulation undoubtedly will be critical in the life definition. The basic philosophy of arriving at load-altitude-temperature lives (through no-load life data as a function of temperature and temperature-rise data) should carry over. The no-load - temperature life data should be taken under severe temperature-cycling conditions that stress any fine wire present (through expansion and contraction).

With these more complicated components, the difficulty of separating catastrophic and gradual failures will become severe. The most promising hope of solution lies in a laboratory-study approach.

A BRIEF DESCRIPTION ON THE LIFE-RATING PROCEDURE FOR COMPOSITION RESISTORS

The Basic Approach

The approach chosen to rate the life of composition resistors may be summarized by the following steps:

- (1) Obtain life of the resistor as a function of ambient temperature for no load.
- (2) Assume that the chief cause of shorter life under load is the higher resistor temperature which results from loading (at least in the short lives⁽¹⁾ of primary interest here).
- (3) Measure the resistor temperature (rather than life) under the various conditions of load and altitude of interest.
- (4) Estimate life for any condition of load and altitude from the data of no-load life versus ambient temperature by correlating with the resistor temperature obtained under the loaded condition.
- (5) Determine the susceptibility of the lives to vibration and humidity.

Consider first the merits of this approach: In the first place, the bulk of tests called for are in Item (1), and no-load life tests at various ambient temperatures are relatively easy to make. In the second place, time-consuming life tests are kept to a minimum, since life is measured primarily at no load, rather than for all possible combinations of load, ambient temperature, and altitude. A further advantage is that the temperature-rise data in Item (3) should be largely independent of resistance values.

The main difficulty in the approach is the validity of the assumption in Item 2. Sufficient care in choosing conservatively the temperature factor of safety⁽²⁾ can yield valid short-term data, even though the assumption may not be theoretically justifiable.

Another difficulty in the basic approach enters in measuring resistor temperature under the abnormal conditions (Item 3).

-
- (1) For long lifetimes, the effect of electrolysis under d-c loads may make such an assumption dangerous.
(2) The "temperature factor of safety" is defined in the discussion that follows.

"Resistor temperature" can mean several things, so it is necessary first to define a few terms.

Let T_d = the effective temperature that causes a resistor to deteriorate,

T_s = the surface temperature of the resistor,

and T_a = the ambient temperature.

It may be well to list a few of the properties of these terms, although some of them are quite obvious.

For the no-load case, after equilibrium at any temperature,

$$T_s = T_d = T_a$$

and is directly measurable.

For the loaded case, resistor temperature varies from the maximum "hot-spot" temperature to various temperatures on the surface.

We shall not concern ourselves here with the "hot-spot" temperature, since it cannot be measured easily. For the terms we have defined,

$$T_d > T_s > T_a;$$

T_a is directly measurable; T_d is not directly measurable; and T_s varies over the surface of the resistor and can be measured.

Then define T_{fs} by the following equation:

$$T_s + T_{fs} = T_d .$$

In words, T_{fs} is the temperature factor of safety to be added to the surface temperature (at a specified location) in order to obtain the effective temperature causing deterioration of the resistor.

The problem has now been reduced to: "How do we measure T_s and T_{fs} ?". Ideally, we would like to know T_s and T_{fs} for all abnormal conditions of interest. Fortunately, the surface temperature, T_s , is easy to measure, so we determine T_s over a range of load, altitude, and ambient temperature (Paragraph E-2a of "Detailed Short-Life-Rating Procedure for Composition Resistors").

Unfortunately, T_{fs} is not measurable directly and must be determined in an indirect manner. Suppose we run a life test for a group of loaded

resistors at a given ambient temperature and measure T_s at the same time. By comparing this measured load life with our no-load curves, we can find the equivalent temperature which is acting under load conditions to produce deterioration. Then, for this condition, $T_{fs} = T_d - T_s$.

We have thus found the temperature factor of safety, T_{fs} , for one particular stressed condition at the expense of running an additional life test. In order to keep life tests to a minimum, we have specified in the detailed procedure that T_{fs} be measured under conditions that produce the maximum internal temperature rise and that this T_{fs} be used for all conditions.⁽¹⁾ Ratings should then be on the conservative side.

In the detailed procedure, we have also specified that T_{fs} be measured for rated load and at twice the rated load for two lifetimes (long and short). A long life and a short life are needed because the mechanisms of failure probably are different.

In determining the life of a stressed resistor by this method, the designer who uses the data probably will choose the temperature factor of safety, T_{fs} , that is largest, and even then he may add a further safety factor, depending on the application envisaged. In trying to determine some relatively accurate estimate of the life of a stressed resistor, the determination of T_{fs} for the two load values and two lifetimes should be of aid. For example, if the application calls for 3X rated load, the T_{fs} estimate will be influenced by the degree to which T_{fs} varies with load (the two measured cases in the procedure are for rated load and twice rated load). Similarly, the T_{fs} estimate will depend on the range of lifetime being considered, and measurement of T_{fs} at the long and short lifetimes should prove informative.

In determining susceptibility to humidity and to vibration, simple no-load stress and cycling tests are prescribed. The effects of the presence of humidity and vibration during life testing have not been tested prior to writing this procedure. It may prove necessary later to elaborate the types of data taken on the effects of these variables.

The Tests and Types of Data Yielded

The basic reasoning behind our approach to the life rating of composition resistors has been presented. Let us now consider more closely the detailed procedure and the tests to be performed.

Paragraphs A through D of the procedure given in the next section specify what resistors are to be measured, and how they are to be selected, treated, mounted, and measured. The accuracies of environmental

(1) Such conditions are those that contribute to maximum convective and radiated heat transfer out the circumference of the resistor, i.e., high pressure, low ambient temperature, and high load.

conditions and measuring equipment are given. Actual tests are described in Paragraph E, and Paragraph F describes the method to be used in obtaining the desired data from the tests. In general, the "desired data" are in the form of average values, with confidence limits to reflect the data variability.

No-load life as a function of ambient temperature (Item (1) under "The Basic Approach") is obtained by the tests of Paragraph E-1. The one-hour stress-step test (Paragraph E-1a) is used to establish a reasonable temperature to start the life tests in order to minimize testing time. The life tests consist of "constant-temperature" tests for lives up to 8 hours (Paragraph E-1b) and "cycling-temperature" tests for lives from 4 hours to 100 hours (Paragraph E-1c).

Lifetime has been defined as the time required for a 5 per cent change in resistance from an initial resistance value at the test temperature. This choice is somewhat arbitrary, but our testing experience indicates this is a reasonable choice⁽¹⁾.

The data on no-load life versus ambient temperature may be thought of as "base-line information" from which all life ratings (even under abnormal conditions) are obtained. These data are to be obtained for both "wet" and "dry" resistors. Typical data for dry resistors might appear as shown in Figure 2.

The load tests (Paragraph E-2) are concerned with Item (3) under "The Basic Approach". In Paragraph E-2a, surface temperature (T_s) is found as a function of ambient temperature for three altitudes: sea level, 30,000 feet, and 60,000 feet. The data obtained for 30,000 feet might appear as shown in Figure 3. Life tests to determine different values of T_{fs} are described in Paragraph E-2b, and the data might appear as in Table 1.

TABLE 1. ILLUSTRATIVE DATA SHOWING HOW THE TEMPERATURE FACTOR OF SAFETY IS OBTAINED

Load (Controlled)	T_a , Ambient Temperature, C (Controlled)	Life, hours (Measured)	T_s , Surface Temperature, C (Measured)	T_d , Effective Temperature Causing Deterioration, C (From Figure 2)	T_{fs} , Temperature Factor of Safety ($T_d - T_s$)
Rated	0	2.3	212	240	28
Rated	-60	57.1	168	198	30
Twice rated	0	1.8	227	258	31
Twice rated	-60	28.3	182	217	34

(1) There is, of course, nothing to prevent obtaining life ratings based on several life definitions by this test procedure. It is obviously imperative, however, that a life rating be associated with a given life definition and method of test. Whether or not it is worth while to obtain and store data for several life definitions and rating methods is a question that must be answered ultimately by the users of the data in ECIC.

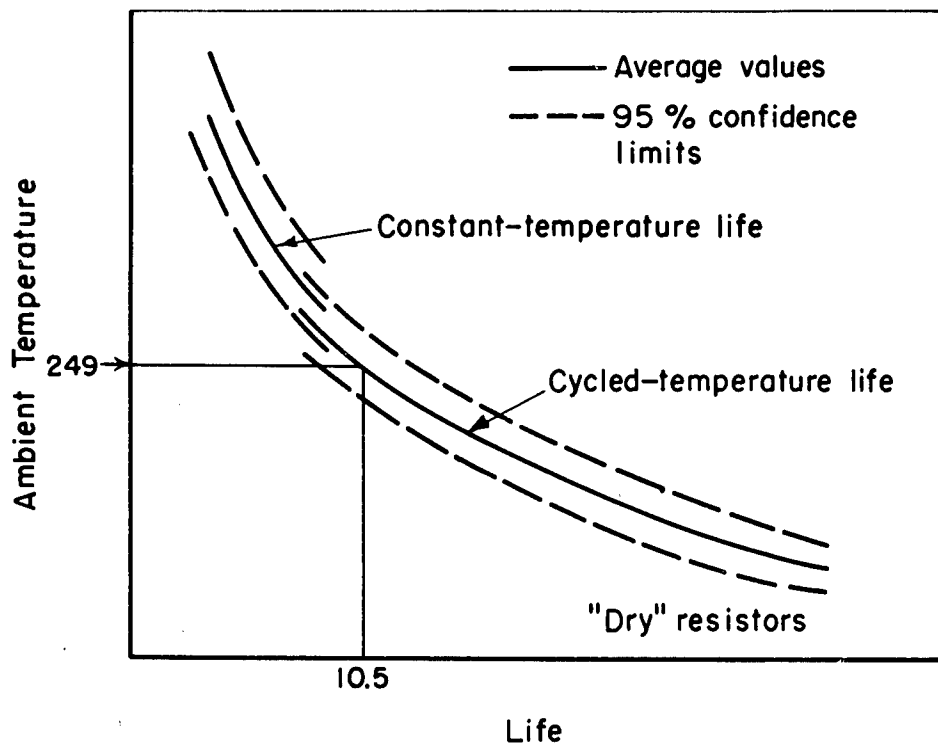


FIGURE 2. ILLUSTRATIVE CURVE SHOWING LIFE VERSUS AMBIENT TEMPERATURE

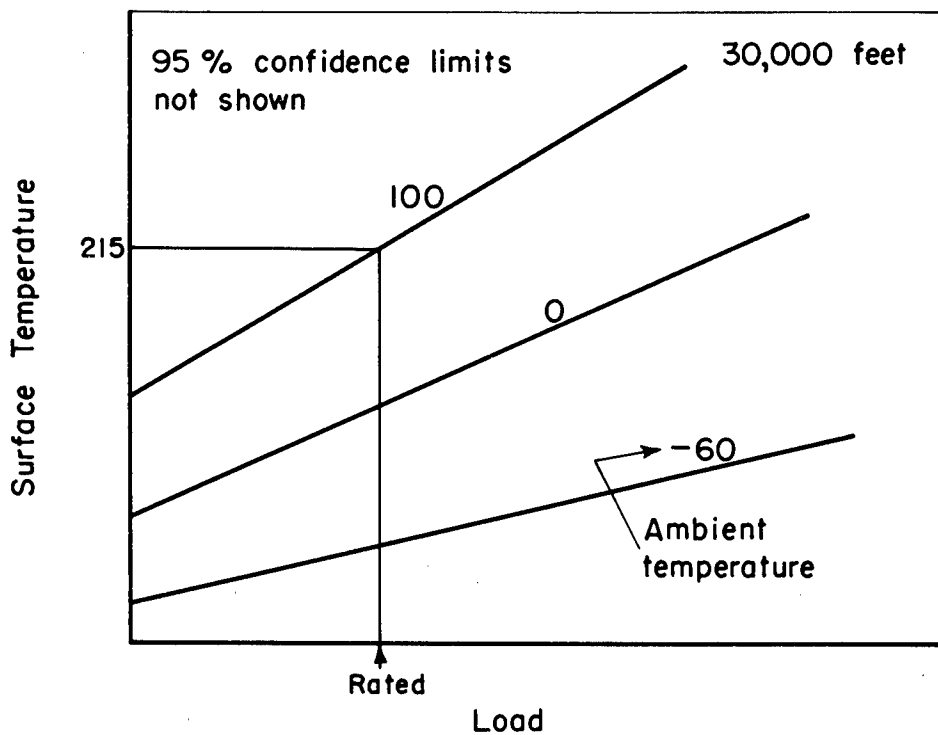


FIGURE 3. ILLUSTRATIVE CURVES SHOWING SURFACE TEMPERATURE VERSUS LOAD FOR THREE AMBIENT TEMPERATURES

Paragraphs E-3 and E-4 illustrate a possible way to determine the susceptibility of the resistors to humidity and vibration deterioration, respectively.

Use of the Data

To illustrate one possible way in which the data obtained from the rating procedure might be used, let us pose a hypothetical problem. Suppose we wish to know how long a resistor will last when operated under the following conditions: 100 C ambient-temperature rated load, 40,000 feet altitude, very little vibration, and very little ambient humidity.

Further, suppose the resistors had been conditioned previously and stored under relatively low-humidity conditions.

The ECIC machines, when properly questioned, will supply the answer by going through the following sequence (indicated on Figures 2 and 3, and Table 1):

- (1) From Figure 3, for 100 C ambient and rated load, $T_s = 215$ C.
- (2) From Table 1, for rated load, choose the highest value of T_{fs} as an added conservative factor. $T_{fs} = 34$ C.
- (3) Adding, $T_d = 215 + 34 = 249$ C.
- (4) From Figure 2, opposite 249 C, estimated life = 10.5 hours.

The next section contains the detailed procedure for obtaining the type of data illustrated here.

DETAILED SHORT-LIFE-RATING PROCEDURE FOR COMPOSITION RESISTORS

A. Applicability

A-1. The resistors covered by this rating procedure are of the carbon-composition type and are suitable for use in communications and electronic equipment.

A-2. The resistors to be tested are described in JAN-R-11, Figures 6 through 21.

B. Environmental Conditions

B-1. Standard Conditions. Measurements made at "room conditions" shall be made at an ambient temperature of 25 ± 5 C (77 ± 9 F), at a barometric pressure of 30 ± 2 inches of mercury, and a relative humidity of less than 50 per cent.

B-2. Extreme Conditions. Unless otherwise indicated, tolerances shall be as follows:

B-2a. Temperature.

- B-2a(1). No-Load Tests. The ambient temperature shall be controlled to plus or minus 2 C throughout the chamber. In the one-hour stress-step test (Paragraph D-1a), the rate of ambient-temperature change within the chamber shall not be less than 2 C per minute.
- B-2a(2). Load Tests. The ambient-temperature-controlling device shall be sensitive to a change in temperature of 2 C. A thermocouple to control ambient temperature shall be mounted on a centrally located resistor which shall not be loaded.
- B-2b. Humidity. The ambient humidity shall be controlled to plus or minus 5 per cent relative.
- B-2c. Vibration.
- B-2c(1). Vibration Amplitude. The vibration amplitude shall be controlled to plus or minus 5 per cent.
- B-2c(2). Vibration Frequency. The frequency of vibration shall be controlled to plus or minus 5 per cent.
- B-2d. Altitude. The altitude shall be controlled to plus or minus 5 per cent in feet.

C. Selection and Conditioning of Samples

C-1. Number of Samples. Test samples for each type of resistor shall consist of approximately 1500⁽¹⁾ resistors of each resistance value indicated by an X in Table VIII of JAN-R-11. Samples of other resistance values shall be tested when it is believed that the life characteristics of other resistance values will be significantly different from the life characteristics of the resistance values in Table VIII of JAN-R-11. All samples shall have a resistance tolerance of plus or minus 5 per cent of the resistance listed. All samples shall be taken from the same manufacturer's "batch". "Batch" refers to resistors manufactured at about the same time from the same mixture of materials.

C-2. Visual and Mechanical Inspection. All resistors shall be inspected visually and mechanically to verify that their physical dimensions, construction, and workmanship are in accordance with the applicable paragraphs of JAN-R-11.

(1) This figure is probably greater than the maximum number of resistors needed. The exact figure is indefinite, since the number of tests depends on the outcome of certain tests.

C-3. Conditioning

- C-3a. No Conditioning. Five per cent of the resistors shall be stored as received under normal room conditions until they are to be tested.
- C-3b. Drying Procedure. Fifty-five per cent of the resistors shall be placed in a drying oven at a temperature of 105 ± 5 C. The resistors shall be removed from the oven at the end of 100 ± 4 hours and stored in a desiccator containing CaSO_4 or activated alumina until they are to be tested.
- C-3c. Wetting Procedure. Forty per cent of the resistors shall be stored as received under normal room conditions until a "base-line temperature", T_1 , is found from Paragraph D-1. These resistors shall then be placed in a drying oven at a temperature of $(T_1 - 40) \text{ C} \pm 3 \text{ C}$. The resistors shall be removed after one hour and placed in humidity chambers at 50 ± 2 C and 95 to 100 per cent relative humidity. They shall remain in the chambers until they are to be tested, but shall be in the chambers a minimum time of 250 hours.

D. Mounting and Methods of Measurement

D-1. No-Load Tests.

- D-1a. Mounting of Resistors. The resistors shall be securely fastened in a horizontal position to lightweight terminals; the effective lead lengths of resistors having wire leads shall be 1 inch. There shall be no undue draft over the resistors. The contact resistance of the connectors shall not change appreciably over the temperature range of testing.⁽¹⁾
- D-1b. Mounting of Thermocouple. One or more resistors of central location shall support a thermocouple junction.
- D-1c. No-Load Voltage. The resistors shall be measured by the application of a direct-current or rms potential for as short a time as practicable in order that the temperature of the resistor shall not rise appreciably during

(1) The highest temperature of testing probably will not exceed 350 C for any make of resistor.

measurement. In no event shall the measurement time for one resistor exceed ten seconds. Test potentials shall be calculated as follows:

$$E_t \leq \sqrt{\frac{P_r R_n}{100}},$$

where:

E_t = d-c or rms, no-load test potential in volts,

P_r = nominal power rating in watts,

and R_n = nominal resistance in ohms.

D-2. Load Tests.

D-2a. Mounting of Resistors. The resistors shall be securely fastened in a horizontal position to lightweight terminals; the effective lead lengths of resistors having wire leads shall be 1 inch. Resistors shall be so arranged that the temperature of any one resistor shall not appreciably influence the temperature of any other resistor. There shall be no undue draft over the resistors. A suitable mounting jig for small-scale testing is shown in Figure 4.

D-2b. Mounting of Thermocouples. All resistors shall support a thermocouple junction resting on the surface hot spot.⁽¹⁾ The thermocouple wires shall hang down on opposite sides of each resistor. Each thermocouple wire shall support a weight of at least 2 ounces. The thermocouple wire shall be calibrated No. 38 AWG⁽²⁾ or smaller.

D-2c. Rated Continuous Working Voltage. Rated continuous working voltage shall be calculated as follows:

$$E_r = \sqrt{P_r R_n},$$

where:

E_r = d-c or rms, rated continuous working voltage in volts,

(1) The temperature-measurement method specified here is taken from MIL 10509. The "surface hot spot" should occur at the center of the resistor on the top side.

(2) American Wire Gage.

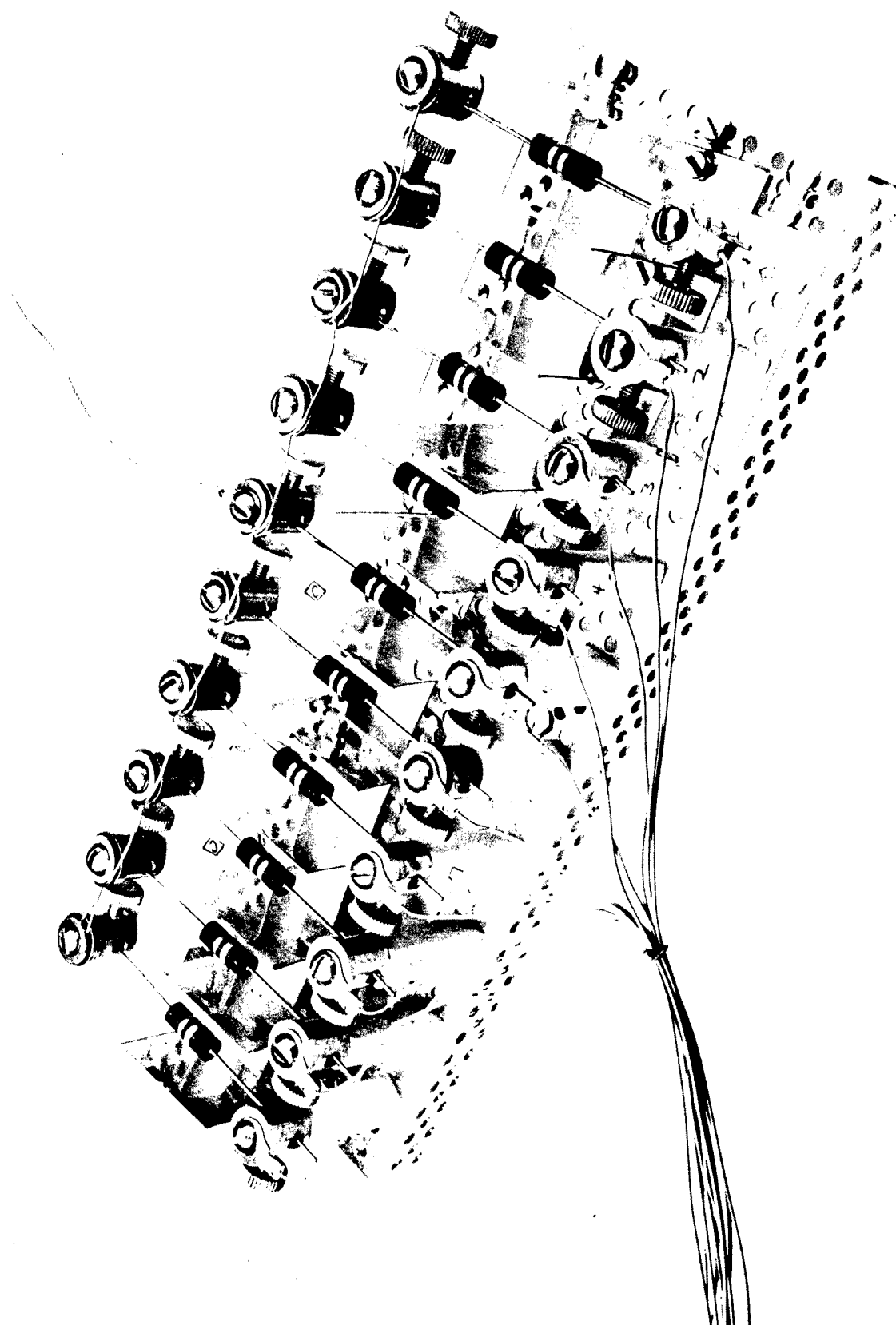


FIGURE 4. RESISTOR JIG FOR LOAD TESTS

P_r = power rating in watts,

and R_n = nominal resistance in ohms.

D-2d. Resistance-Measuring Circuits.

D-2d(1). Circuit for Temperature-Altitude Tests. A circuit for measuring loaded resistors which has been used successfully in performing surface-temperature tests is given in Figure 5a. As shown in the figure, one power supply may be used to supply all the resistors simultaneously.

D-2d(2). Circuit for Load-Life Tests. A circuit for measuring loaded resistors which has been used successfully in performing load-life tests is given in Figure 5b. As shown in the figure, each resistor shall be supplied by a separate power supply.

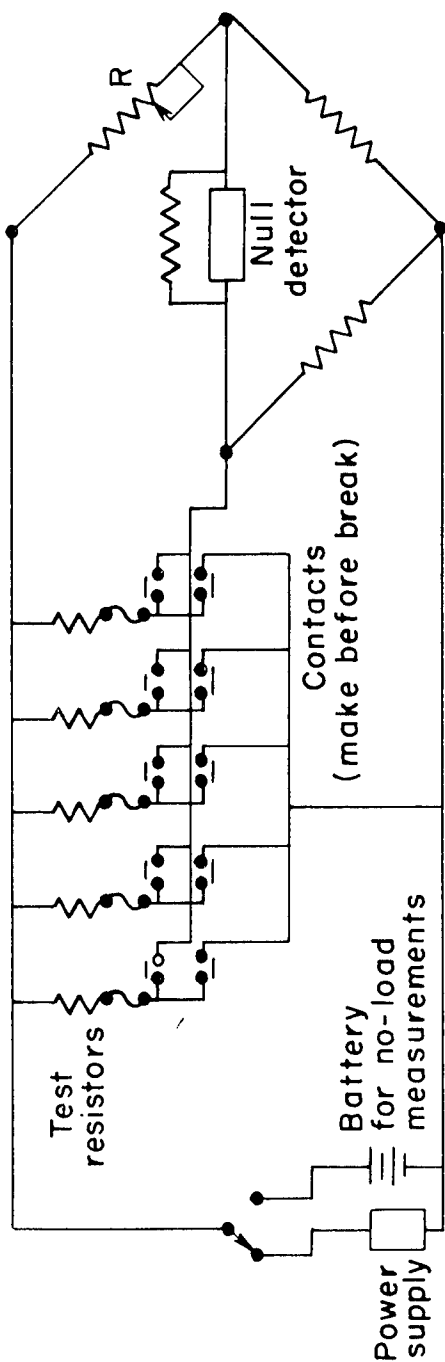
D-3. Accuracy of Test Equipment.

D-3a. Resistance. The maximum error of test equipment used in making resistance measurements shall not exceed 0.5 per cent.

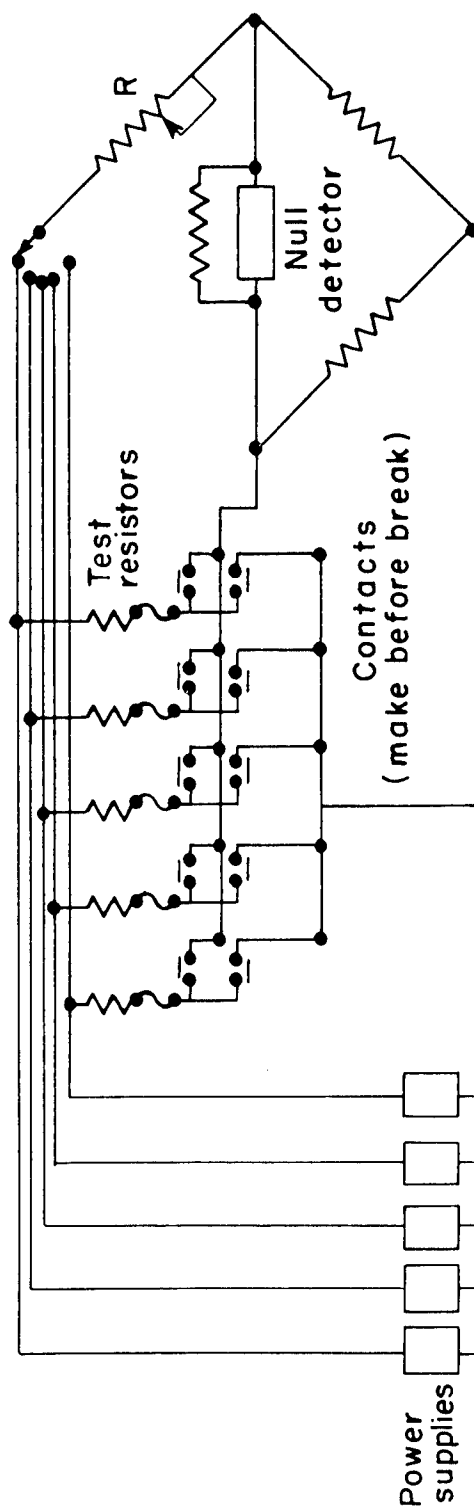
D-3b. Surface Temperature. The maximum error in measurement of surface temperature shall not exceed plus or minus 2 C.

D-4. "Resistor Stability" and "Zero Time".

D-4a. Definitions. "Stress" is applied to resistors in this test procedure in the form of ambient temperature and/or load under different conditions of humidity, vibration, and altitude. When a resistor is "stressed", its surface temperature and resistance may change rapidly at first, and then much more slowly. "Resistor stability" shall refer to the condition of a stressed resistor when surface temperature and resistance have reached the end of the initial rapid change. "Zero time" shall refer to the time when "resistor stability" occurs. In cases where "resistor stability" is not clearly obvious from the monitored resistor, "zero time" shall be 20 minutes after the stress is applied, or 20 minutes after the stress is changed from one level to another.



a. Circuit for Surface-Temperature Tests



b. Circuit for Load-Life Tests

FIGURE 5. MEASURING CIRCUITS FOR LOADED RESISTORS

A-7115

- D-4b. Measurements. Resistor stability shall be determined by visual observation of the surface temperature and resistance of a centrally located resistor whose surface temperature and resistance are continuously monitored. The bridge of Figure 5 has been used for continuously monitoring resistance. The null detector was a self-balancing Brown Electronik Potentiometer. The slide wire of the Brown was replaced by R, a linear potentiometer geared to the drive mechanism of the pointer.

E. Test Procedures

E-1. No-Load Tests.

E-1a. One-Hour Stress-Step Test

- E-1a(1). Preparation. Ten resistors which have been dried according to Paragraph C-3b shall be mounted according to Paragraph D-1a and measured at room conditions. The temperature chamber shall be preheated to 100 C.

- E-1a(2). Test Method. The mounted resistors shall be inserted in the preheated chamber. Temperature and resistance values shall be recorded at "zero time" according to Paragraph B-4, and at succeeding 15-minute intervals. After four readings (1 hour from "zero time"), the chamber temperature shall be raised by 10 C.

Temperature and resistance values shall be recorded at the new "zero time" and at succeeding 15-minute intervals. After four readings (1 hour from the new "zero time"), the chamber temperature shall be raised by 10 C.

The above steps shall be repeated until at least five of the 10 resistors have "failed". The temperature of the step at which five or more of the resistors have failed shall be recorded as T_1 , the base-line temperature.

- E-1a(3). Failures. A resistor "failure" occurs in this test when the change in resistance during the interval from any "zero time" to the succeeding 1-hour reading is equal to or greater than 5 per cent.

E-1b. Eight-Hour Constant-Temperature Tests.

- E-1b(1). Tests of Dried Resistors.

- E-1b(1)a. Preparation. Twenty resistors which have been dried according to Paragraph C-3b shall be mounted according to Paragraph D-1a and measured at room conditions. The temperature chamber shall be preheated to T_1 , the base-line temperature, as determined from Paragraph D-1a.
- E-1b(1)b. Test Method. The mounted resistors shall be inserted in the preheated chamber. Temperature and resistance values shall be recorded at "zero time" according to Paragraph D-4, and at succeeding 15-minute intervals. The test shall continue until either all resistors have "failed" or 8 hours have elapsed since "zero time".
- E-1b(1)c. Failures. A resistor "failure" occurs in this test when the change in resistance from "zero time" is equal to or greater than 5 per cent.
- E-1b(1)d. Further Tests. The procedure given by Paragraphs E-1b (1)a, E-1b (1)b, and E-1b (1)c shall be followed with 20 different resistors, except that the chamber temperature shall be 20 C lower. Succeeding tests with different resistors for each test shall follow. The chamber temperature for each succeeding test shall be 20 C lower than that of the previous test. For example, the chamber temperature in the test described by Paragraphs E-1b (1)a through E-1b (1)c shall be T_1 C; the chamber temperatures for the following tests shall be $(T_1 - 20)$ C, $(T_1 - 40)$ C, $(T_1 - 60)$ C,

Tests shall continue until no resistor failure occurs during the 8-hour period of one test.

- E-1b(2). Test of Wet Resistors. All tests described by Paragraph E-1b (1) shall be repeated, except that resistors which have been wet according to Paragraph C-1c shall be used. Tests shall be performed again as described by Paragraph E-1b (1)d until no "wet"-resistor failure occurs during the 8-hour period of one test.
- E-1b(3). Test of Resistors As Received. The first test described by Paragraph E-1b (1) (chamber temperature = T_1) shall be repeated, except that resistors which have been stored according to Paragraph C-3a shall be used.

E-1c. Temperature-Cycling Tests.

E-1c(1). Tests of Dried Resistors.

E-1c(1)a. Preparation. Twenty resistors which have been dried according to Paragraph C-3b shall be mounted according to Paragraph D-1a and measured at room conditions. The temperature chamber shall be preheated to $(T_1 - 40)^\circ\text{C}$, where T_1 is determined from Paragraph D-1a.

E-1c(1)b. Test Method. The mounted resistors shall be inserted in the preheated chamber. Temperature and resistance values shall be recorded at "zero time" according to Paragraph B-4, and at succeeding 15-minute intervals. After eight readings (2 hours from "zero time"), the mounted resistors shall be removed from the chamber and allowed to cool under room conditions. After a minimum time of 1/2 hour⁽¹⁾ under room conditions, the resistors shall be measured.

The resistors shall again be inserted in the chamber, which shall be at $(T_1 - 40)^\circ\text{C}$. Temperature and resistance values shall be recorded at the new "zero time" and at succeeding 15-minute intervals. After eight readings (2 hours from the new "zero time"), the mounted resistors shall again be removed from the chamber and allowed to cool under room conditions. The chamber shall be maintained at $(T_1 - 40)^\circ\text{C}$. After a minimum time of 1/2 hour under room conditions, the resistors shall be measured.

The cycle above, consisting of a "2-hour-in" period followed by a "1/2-hour-out" period, shall be continued until either all resistors have failed or 50 cycles have been completed.

E-1c(1)c. Failures. A resistor "failure" occurs in this test in either or both of two ways: (1) when the change in resistance during the interval from any "zero time" to the succeeding 2-hour reading is equal to or greater than 5 per cent (see Paragraph F-3a), or when the change in resistance from the original value under room conditions (Paragraph E-1c (1)a) to any succeeding value under room conditions is equal to or greater than 5 per cent (see Paragraph F-3b).

(1) The maximum time under room conditions shall not exceed 66 hours.

E-1c(1)d. Further Tests. The procedure given by Paragraphs E-1c (1)a, E-1c (1)b, and E-1c (1)c shall be followed with twenty different resistors, except that the chamber temperature shall be 20 C lower. Succeeding tests with different resistors for each test shall follow. The chamber temperature for each succeeding test shall be 20 C lower than that for the previous test. For example, the chamber temperature in the test described by Paragraphs E-1c (1)a through E-1c (1)c shall be $(T_1 - 40)$ C; the chamber temperatures for the following tests shall be $(T_1 - 60)$ C, $(T_1 - 80)$ C, $(T_1 - 100)$ C,

Tests shall continue until no resistor failure occurs during the full 50 cycles of one test.

E-1c(2). Tests of Wet Resistors. All tests described by Paragraph E-1c (1) shall be repeated, except that resistors which have been wet according to Paragraph B-1c shall be used. Tests shall be performed again as described by Paragraph E-1c (1)d until no "wet"-resistor failure occurs during the full 50 cycles of one test.

E-1c(3). Test of Resistors as Received. The first test described by Paragraph E-1c (1) (chamber temperature = T_1) shall be repeated, except that resistors which have been stored according to Paragraph C-3a shall be used.

E-2. Load Tests.

E-2a. Temperature-Altitude Tests.

E-2a(1). Preparation. Ten resistors which have been dried according to Paragraph C-3b shall be mounted according to Paragraph D-2a and measured at room conditions. The temperature-altitude chamber shall be precooled to minus 60 C at sea-level pressure, as shown in the first row of Table 2.

E-2a(2). Test Method. The mounted resistors shall be inserted in the precooled chamber. Fifty per cent rated voltage (Paragraph D-2c) shall be applied to the resistors according to Paragraph D-2d (1). The temperature and resistance values shall be recorded at "zero time" according to Paragraph D-4.

The voltage applied shall then be increased to 75 per cent rated voltage. The temperature and resistance values shall be recorded at the new "zero time". The voltage shall be increased in successive steps of 25 per cent following temperature and resistance readings at "zero time", until the surface temperature of one or more resistors is equal to or greater than 280 C.

E-2a(3). Further Tests. The procedure given by Paragraphs E-2a (1) and E-2a (2) shall be followed for the remaining ambient-temperature and altitude conditions given in Rows 2 through 9 of Table 2. Different resistors shall be used for each of the remaining eight tests.

TABLE 2. SURFACE-TEMPERATURE TEST CONDITIONS

Row Number	Ambient Temperature, C	Altitude, feet above sea level
1	-60	0
2	0	0
3	100	0
4	-60	30,000
5	0	30,000
6	100	30,000
7	-60	60,000
8	0	60,000
9	100	60,000

E-2b. Load-Life Tests.

E-2b(1). Eight-Hour Constant-Temperature Test.

E-2b(1)a. Preparation. Five resistors which have been dried according to Paragraph C-3b shall be mounted according to Paragraph D-2a and measured at room conditions. The temperature chamber shall be preheated to 100 C.

E-2b(1)b. Test Method. The mounted resistors shall be inserted in the preheated chamber. The temperature and resistance values shall be recorded at "zero time" according to Paragraph D-4. A voltage necessary for rated power shall be estimated for each resistor from the relation:

$$E_e = \sqrt{P_r R_{nl}} ,$$

where E_e = estimated voltage for rated power in volts,

P_r = nominal power rating in watts,

and R_{nl} = no-load resistance value at "zero time" in ohms.

The estimated voltage for rated power shall be applied to each resistor with a separate power supply according to Paragraph D-2d(2). Resistance measurements shall be made and voltages adjusted until each resistor is dissipating rated power. Temperature and resistance values shall be recorded at the new "zero time" according to Paragraph D-4, with the further requirement that each resistor must be dissipating rated power.

At 15-minute intervals after the new "zero time", resistance and temperature values shall be recorded and voltages adjusted for maintaining rated power in each resistor. The test shall continue until either all resistors have "failed" or 8 hours have elapsed since the new "zero time".

E-2b(1)c. Failure. A resistor "failure" occurs in this test when the change in resistance from the new "zero time" is equal to or greater than 5 per cent.

E-2b(1)d. Further Test. The procedure given by Paragraphs E-2b (1)a, E-2b (1)b, and E-2b (1)c shall be followed with five different resistors, except that twice rated power shall be used, in place of rated power.

E-2b(2). Temperature- and Load-Cycling Tests.

E-2b(2)a. Preparation. Five resistors which have been dried according to Paragraph C-3b shall be mounted according to Paragraph D-2a and measured at room conditions. The temperature chamber shall be precooled to -60 C.

E-2b(2)b. Test Method. The mounted resistors shall be inserted in the precooled chamber. The temperature and resistance values shall be recorded at "zero time"; the voltage necessary for rated power shall be estimated, applied, and adjusted with separate power supplies; and the resistance and temperature values shall be recorded at the new "zero time" in the same manner as described in Paragraph E-2b (1)b.

At 15-minute intervals after the new "zero time", resistance and temperature values shall be recorded and voltages adjusted to maintain rated power in each resistor. After eight readings (2 hours from the new "zero time"), the load shall be removed from each resistor and the mounted resistors shall be removed from the chamber and allowed to assume room conditions. The chamber shall be maintained at -60 C. After a minimum time of 1/2 hour under room conditions, the resistors shall be measured.

The resistors shall again be inserted in the chamber. Measurements and application of load shall be made again as described above, followed by removal of load and removal of the resistors to room conditions.

The cycle consisting of a "2-hour-in" period followed by a "1/2-hour-out" period shall be continued until either all resistors have failed or 50 cycles have been completed.

E-2b(2)c. Failures. A resistor "failure" occurs in this test in either or both of two ways: (1) when the change in resistance during the interval from any new "zero time" to the succeeding 2-hour reading is equal to or greater than 5 per cent, or (2) when the change in resistance from the original value under room conditions (Paragraph E-2b (2)a) to any succeeding value under room conditions is equal to or greater than 5 per cent.

E-2b(2)d. Further Test. The procedure given by Paragraphs E-2b (2)a, E-2b (2)b, and E-2b (2)c shall be followed with five different resistors, except that twice rated power shall be used, in place of rated power.

E-3. Humidity Tests.

E-3a. One-Hour Stress-Step Test. The procedure given by Paragraphs E-1a (1), E-1a (2), and E-1a (3) shall be followed, except that the relative humidity shall be 95 to 100 per cent. The temperature of the step where

at least five of the ten resistors have failed shall be recorded as T_1' , the base-line temperature for high humidity.

E-3b. Temperature-Cycling Test. The procedure given by Paragraphs E-1c (1)a, E-1c (1)b, and E-1c (1)c shall be followed, except that the relative humidity shall be 95 to 100 per cent.

E-4. Vibration Test.

E-4a. One-Hour Stress-Step Test. The procedure given by Paragraphs E-1a (1), E-1a (2), and E-1a (3) shall be followed, with the further requirement that the resistors be vibrated continuously with a simple harmonic motion having an amplitude of 0.03 inch (maximum excursion 0.06 inch) and a frequency of 60 cycles per second. The temperature of the step where at least five of the ten resistors have failed shall be recorded as T_1'' , the base-line temperature for vibration.

F. Extraction of Data for ECIC

F-1. No-Load One-Hour Stress-Step Test (Paragraph E-1a).

F-1a. Record for ECIC. The "base-line temperature", T_1 , where at least 5 of the 10 resistors fail shall be recorded.

F-2. No-Load Eight-Hour Constant-Temperature Test (Paragraph E-1b).

F-2a. Resistance-Temperature Characteristic.

F-2a(1). Transformation of Data. The initial ratio R_i/R_o shall be determined for each of the 20 resistors in each of the tests performed according to Paragraph E-16, where

R_i = initial resistance at "zero time" (at test temperature),

and R_o = original resistance at room temperature.

F-2a(2). Calculations.

F-2a. (2)a Average Values. For each test, determine an average ratio,

$$(R_i/R_o)_{\text{avg}} = \frac{\left(\frac{R_i}{R_o}\right)_1 + \left(\frac{R_i}{R_o}\right)_2 + \dots + \left(\frac{R_i}{R_o}\right)_{20}}{20},$$

where

$\left(\frac{R_i}{R_o}\right)_1$ = initial resistance ratio for the first resistor,

$\left(\frac{R_i}{R_o}\right)_2$ = initial resistance ratio for the second resistor.

etc.

F-2a(2)b. Confidence Limits. Calculate 95 per cent confidence limits for the initial-ratio average by the method given by Brownlee.⁽¹⁾

F-2a(3). Record for ECIC. Record initial-ratio averages and 95 per cent confidence limits for "as-received", "dried", and "wet" resistors against temperature for each 8-hour test. These data provide temperature characteristic curves for each type resistor.

F-2b. Life Versus Temperature.

F-2b(1). Original Life Data. For each test, determine the life of each resistor as the time elapsed from "zero time" to "failure" time to an accuracy of ± 0.02 hour.⁽¹⁾ Where a resistor does not fail within 8 hours, determine an estimate of the life by linear extrapolation as follows:

$$\text{Life (est.)} = 8 \times \frac{5 R_i}{100 | (R_g - R_i) |}$$

where R_i is the original resistance at test temperature and R_g is the resistance value 8 hours after "zero time". Where the estimated life is greater than 20 hours, the value "20 hours" shall be used in further calculations.

(1) It will be necessary to obtain these data from plotted curves unless the lifetimes for both the load and no-load tests happen to be experimental points.

F-2b(2). Transformation of Life Data. The logarithm of each life value in Paragraph F-2b (1) shall be found.

F-2b(3). Average Life. For each test, determine average life as follows:

$$\text{Life (avg)} = \frac{L_1 + L_2 + \dots + L_{20}}{20},$$

where $L_1 + L_2 + \dots + L_{20}$ is the summation of the logarithmically transformed lives of individual resistors.⁽¹⁾

F-2b(4). Confidence Limits. Ninety-five per cent confidence limits on the average lives shall be found by the method given by Brownlee.

F-2b(5). Record for ECIC. Record average life values and 95 per cent confidence limits for "as-received", "dried", and "wet" resistors. These are the data for the curves of no-load life versus temperature, up to 8 hours.

F-3. No-Load Temperature-Cycling Tests (Paragraph E-1c).

F-3a. Temperature Versus Life for Resistors Failing While Stressed.

F-3a(1). Original Life Data. For each test, determine the life of each resistor as the cumulative time elapsed from any "zero time" to the succeeding "failure" time to an accuracy of ± 0.02 hour⁽¹⁾, where a "failure" occurs when the change in resistance during the interval from any "zero time" to the succeeding 2-hour reading is equal to or greater than 5 per cent. Where a resistor does not fail within 100 hours' accumulated time, determine an estimate of the life by linear extrapolation as follows:

$$\text{Life (est.)} = 100 \times \frac{5 R_i}{100|(R_{100} - R_i)|}$$

(1) It will be necessary to obtain these data from plotted curves unless the lifetimes for both the load and no-load tests happen to be experimental points.

where R_i is the original resistance at test temperature and R_{100} is the resistance value after 100 hours' accumulated time at test temperature. Where the estimated life is greater than 200 hours, the value "200 hours" shall be used for further calculations.

F-3a(2). Transformation of Life Data. The logarithm of each life value in Paragraph F-3a (1) shall be found.

F-3a(3). Average Life. For each test, determine average life as follows:

$$\text{Life (avg.)} = \frac{L_1 + L_2 + \dots + L_{20}}{20},$$

where $L_1 + L_2 + \dots + L_{20}$ is the summation of the logarithmically transformed lives of individual resistors.

F-3a(4). Confidence Limits. Ninety-five per cent confidence limits on the average lives shall be found by the method given by Brownlee.

F-3a(5). Record for ECIC. Record average life values and 95 per cent confidence limits for "as-received", "dried", and "wet" resistors. These are the data for the curves of no-load life versus temperature, cycled, 4 to 100 hours.

F-3b. Temperature Versus Life for Resistors Failing When Returned to Room Conditions.

F-3b(1). Original Life Data. For each test, determine the life of each resistor as the cumulative time elapsed from any "zero time" to the succeeding "failure" time to an accuracy of ± 0.02 hours⁽¹⁾, where a "failure" occurs when the change in resistance from the original value under room conditions to any succeeding value under room conditions is equal to or greater than 5 per cent. Where a resistor does not fail within 100 hours' accumulated time, determine an estimate of the life by linear extrapolation as indicated in Paragraph F-3a (1).

(1) It will be necessary to obtain these data from plotted curves unless the lifetimes for both the load and no-load tests happen to be experimental points.

- F-3b(2). Transformation of Life Data. The logarithm of each life value in Paragraph F-3b (1) shall be found.
- F-3b(3). Average Life. Follow procedure outlined in Paragraph F-3a (3) above.
- F-3b(4). Confidence Limits. Follow the procedure outlined in Paragraph F-3b (4).
- F-3b(5). Record for ECIC. Follow the procedure outlined in Paragraph F-3a (5).

F-4. Load-Temperature-Altitude Tests (Paragraph E-2a).

- F-4a. For the conditions in the first row of Table 2 (60 C ambient temperature and 0 feet of altitude), calculate the actual power in each resistor from the relation:
Actual Power = $P_a = E_a^2/R$, where

R = measured resistance,

E_a = applied voltage (successively equal to 0.50 E_r , 0.75 E_r , etc., as specified in Paragraph E-2a (2)).

- F-4b. Curves. Plot the measured surface temperature versus actual power for each resistor. Draw a straight line from the origin (zero power and surface temperature equal to ambient temperature) to the first experimental point. Draw straight lines between experimental points.
- F-4c. Surface Temperature. From the plot of each resistor described in Paragraph F-4b, determine the surface temperature for the following actual power values: 0.25 P_r , 0.50 P_r , 0.75 P_r , etc. (increase in 25 per cent steps to the limit of the data as determined by Paragraph E-2a (2), where P_r is the (nominal) power rating of the resistor).
- F-4d. Average Surface Temperature. For each actual power value in Paragraph F-4c, determine average surface temperature as follows:

$$\text{Surface Temperature (avg)} = \frac{T_{s1} + T_{s2} + \dots + T_{s10}}{10},$$

where $T_{s1} + T_{s2} + \dots + T_{s10}$ is the summation of the surface temperatures for individual resistors.

- F-4e. Confidence Limits. Find 95 per cent confidence limits on each average surface temperature by the method given by Brownlee.
- F-4f. Further Calculations. Repeat Paragraphs F-4a through F-4e for the conditions given by Rows 2 through 9 of Table 2.
- F-4g. Record for ECIC. Record average surface temperature (for each actual power) and 95 per cent confidence limits for each condition of ambient temperature and altitude given by Table 2.
- F-5. Load-Life Tests (Paragraph E-2b).
- F-5a. Original Life Data, Average Life, Transformation of Life Data. Repeat Paragraph F-2b for both load conditions for "dried" resistors only.
- F-5b. Extraction of " T_{fs} Values⁽¹⁾. Calculate T_{fs1} by subtracting the average surface temperature obtained with rated load (Paragraphs E-2b (1)a through E-2b (1)c) from the ambient temperature corresponding to the same lifetime under no load (Paragraph E-1b (2)).⁽²⁾ Calculate T_{fs2} by subtracting average surface temperature obtained with twice rated load (Paragraph E-2b (1)d) from the ambient temperature corresponding to the same lifetime under no load (Paragraph E-1b (2)).⁽²⁾
- F-5c. Record for ECIC. Record average life values and 95 per cent confidence limits for "dried" resistors. Record T_{fs1} , the temperature factor of safety for rated load and short life. Record T_{fs2} , the temperature factor of safety for twice rated load and short life.

(1) The symbol T_{fs} is used to designate the difference between average surface temperature for loaded resistors and ambient temperature for resistors under no load, where the loaded and unloaded resistors have the same lifetimes.

(2) It will be necessary to obtain these data from plotted curves unless the lifetimes for both the load and no-load tests happen to be experimental points.

F-6. Temperature- and Load -Cycling Tests (Paragraph F-2b (2)).

- F-6a. Original Life Data, Average Life, Transformation of Life Data. Repeat Paragraph F-3 for both load conditions for "dried" resistors only.
- F-6b. Extraction of " T_{fs3} " Values. Calculate T_{fs3} by subtracting the average surface temperature for the "2-hour-on" periods obtained with rated load (Paragraphs E-2b (2)a through E-2b (2)c) from the ambient temperature corresponding to the same lifetime under no load (Paragraph E-1c (2)).⁽¹⁾
- F-6c. Record for ECIC. Record average life values and 95 per cent confidence limits for "dried" resistors. Record T_{fs3} , the temperature correction for rated load and long life. Record T_{fs4} , the temperature factor of safety for twice rated load and long life.

F-7. Humidity Tests (Paragraph E-3a).

- F-7a. One-Hour Stress-Step Test. The "base-line temperature with humidity", T_1' , where at least 5 of the 10 resistors have failed, shall be recorded.⁽²⁾
- F-7b. Temperature-Cycling Test (Paragraph E-3b). Repeat Paragraph F-3.

F-8. Vibration Tests.

- F-8a. One-Hour Stress-Step Test (Paragraph E-4a). The "base-line temperature with vibration", T_1'' , where 5 of the 10 resistors fail, shall be recorded.⁽³⁾

-
- (1) It will be necessary to obtain these data from plotted curves unless the lifetimes for both the load and no-load tests happen to be experimental points.
- (2) The ECIC engineer shall compare T_1 with T_1' , and cycling-life values with and without humidity. He shall record "susceptible" to humidity if appreciable differences are noted, and "not susceptible" to humidity if no significant differences are noted.
- (3) The ECIC engineer shall compare T_1 with T_1'' . He shall record "susceptible" to vibration or "not susceptible" to vibration, depending on the difference between T_1 and T_1'' .

EXPERIMENTAL RESULTS

This section reports the tests which were performed after September 30, 1951, in order to develop a reasonable life-rating procedure. The tests in each subsection (such as the first subsection, "Stress-Step Tests on Carbon-Composition Resistors") are presented somewhat chronologically. The order of the subsections, however, is only approximately chronological, since much of the work was carried on simultaneously with different setups and personnel.

A previous report (supplement to the Thirteenth Interim Engineering Report from Battelle to WPAFB, dated February 29, 1952) gave some results of no-load life tests of predried resistors. The conclusion reached was that "composition resistors are too variable to obtain useful life ratings by the rating procedure used". The "rating procedure used" has been described as a "life-at-temperature" procedure and consists of the following steps:

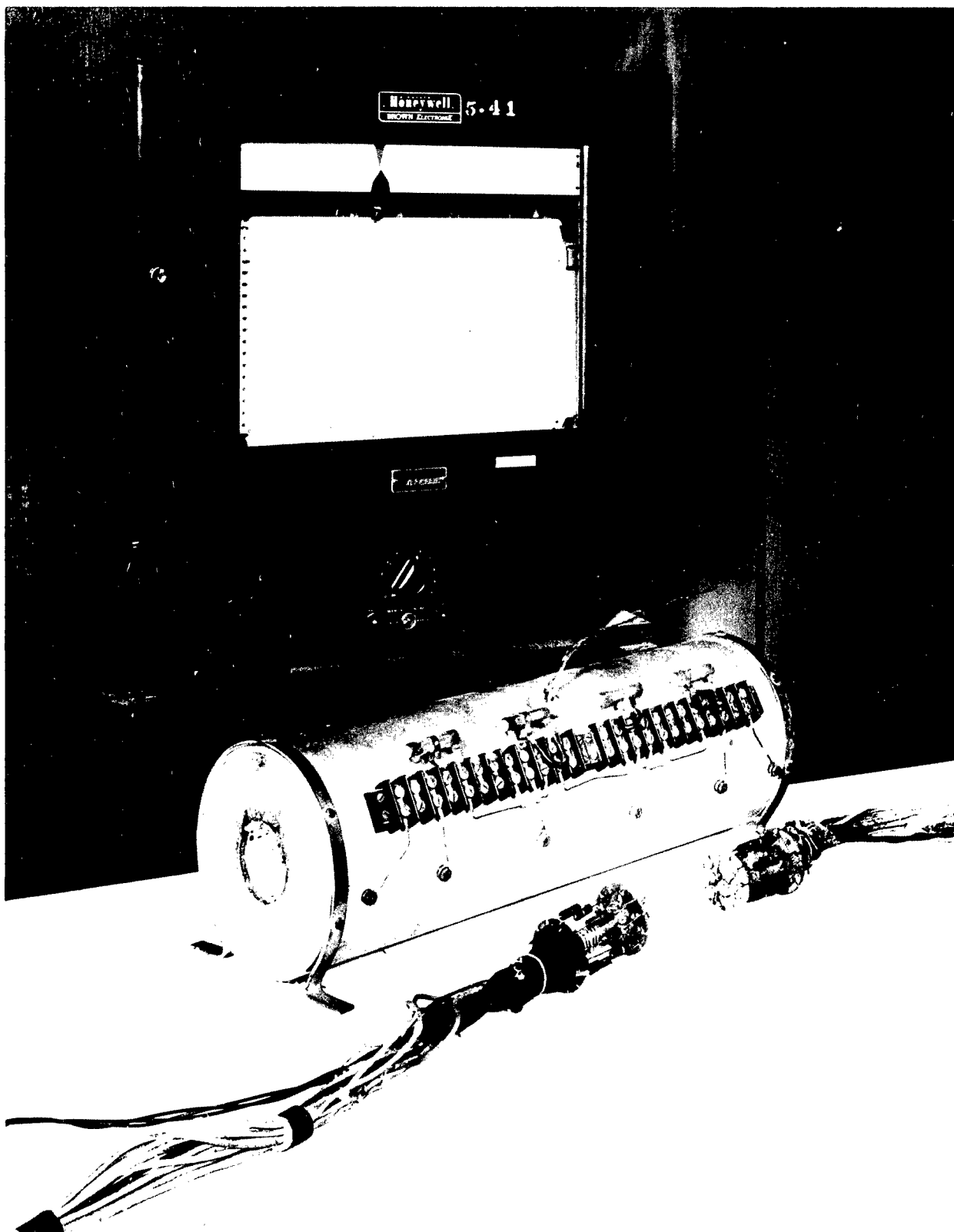
- (1) Insert resistors in a preheated oven.
- (2) Measure resistance as a function of time.
- (3) Assign a life rating for the resistors, depending on the time required for a given percentage change in resistance from an initial value at oven temperature.

The more promising "step test" method was proposed as being worthy of evaluation by actual tests. This evaluation is given in the first subsection that follows. Evaluation of a variation of step testing is given in the second subsection that follows.

Stress-Step Tests on Carbon Resistors

Method and Equipment

Most of the tests described were run in the small circular oven of Figure 6, which is ideal for no-load step testing because of its low thermal inertia. A Brown Electronik Temperature Controller, Type 153R10P-141-20, was used to control and step up temperature. The controller is of the



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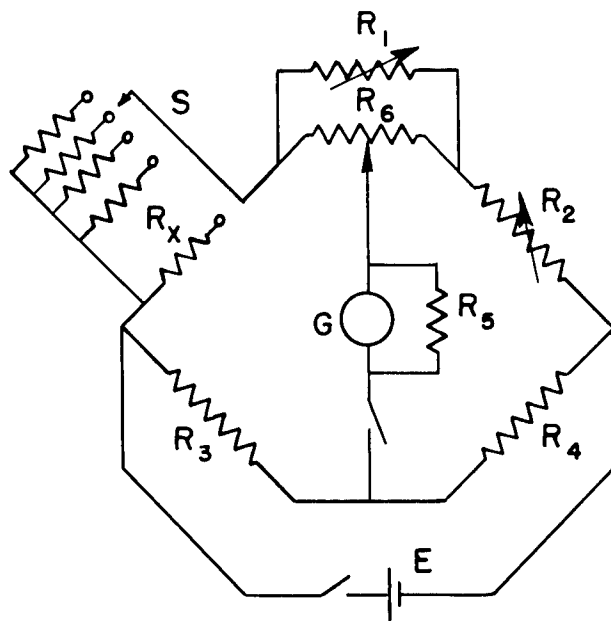
FIGURE 6. OVEN, RESISTOR JIGS, AND TEMPERATURE CONTROLLER
USED IN NO-LOAD STEP TESTING

"proportional off-on" type. It varies the time of current to the oven in accordance with oven needs. By making the proper manual adjustment on the front panel during a test, minimum temperature-rise time with no overshoot can be obtained. Temperature control is better than ± 2 C. Temperature was measured with several 20-gage Chromel-Alumel thermocouples mounted on the resistor jigs and was read on a separate Brown Electronik Recorder. Temperature gradients longitudinally in the oven were minimized by adjusting the variable resistors in parallel with segments of the oven windings. The temperature differences among resistors in most tests was less than ± 5 C.

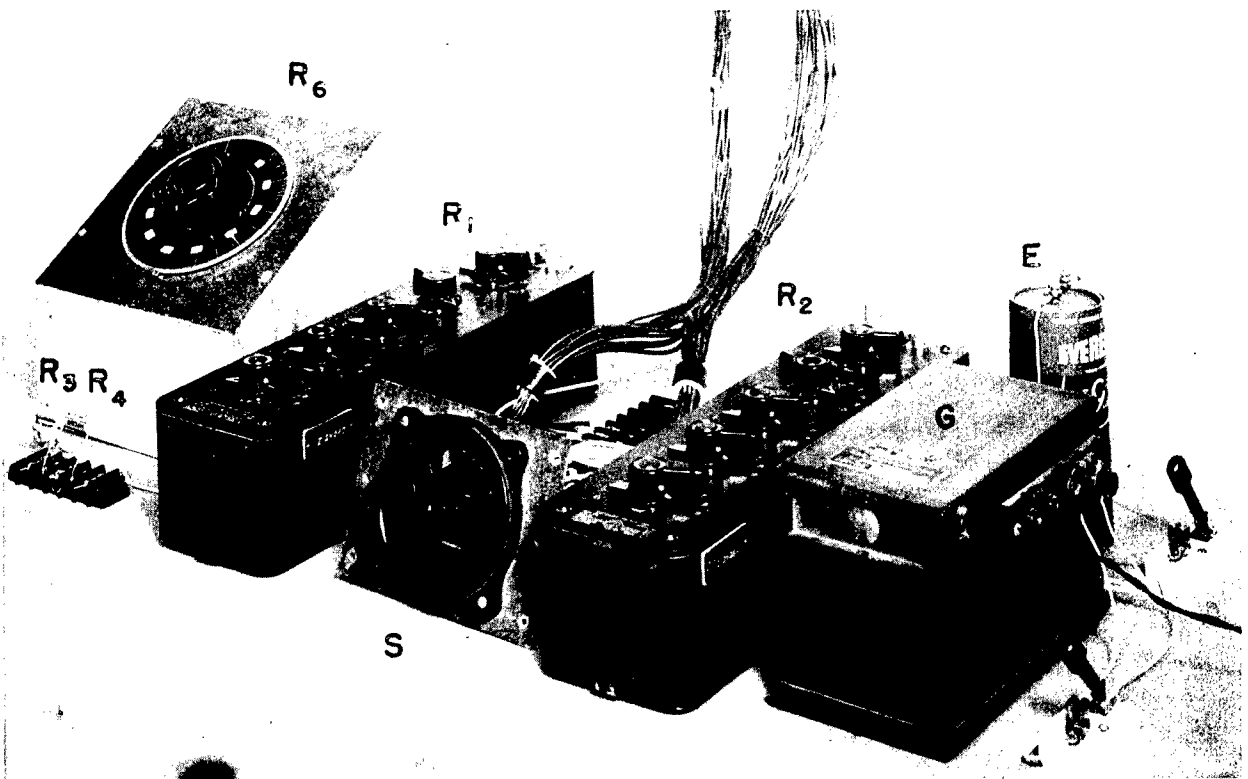
In the foreground of Figure 6 are the two resistor jigs used. Each jig holds twelve resistors. They are similar to the jig shown in detail in Figure 7, page 26, of the Thirteenth Interim Engineering Report, except that transite end disks are used, rather than brass. Also, twelve resistors can be mounted, rather than four.

Resistance was measured by the modified Wheatstone bridge circuit shown schematically in Figure 7a. By testing only one resistance value in a given life test (100,000 ohms, in most of our tests), measurement time is reduced by avoiding range changes. The components of the bridge circuit are shown in the photograph, Figure 7b. A selector switch is changed manually to insert individual resistors in the R_x branch. The potentiometer R_6 is rotated for balance (null is indicated by the galvanometer, G), and its calibrated dial is read directly in thousands of ohms. R_1 is adjusted for proper dial calibration. R_2 allows a restricted range change. The accuracy of resistance measurements near 100,000 ohms is ± 0.25 per cent, and is never less than 1.0 per cent. Accuracy is limited by the linearity of R_6 . The effect of thermal emf's in the measuring circuit was found to be negligible.

A major problem in making life tests has been to obtain a consistent starting point from which to measure life. If we choose to define life as the time required for the resistor to exceed certain limits at the operating temperature, the rise time to temperature becomes critically important. This has been discussed in some detail in the Thirteenth Interim Engineering Report, page 3. The "initial hot resistance value" can be used as the starting point in measuring life. This is the resistance value when the resistor first reaches operating temperature. Figure 1 shows graphically how life is measured from the initial hot resistance value (Point b). For uniform temperature distribution in the oven, the time for different resistors to reach their initial hot resistance value varies only slightly. We found that "A" and "B" resistors require about 12 minutes to heat up internally when the ambient temperature is raised by 10 C in the temperature range of our studies. "C" resistors take about 5 minutes. In our life tests, we



a. Schematic



b. Photograph

FIGURE 7. MODIFIED WHEATSTONE BRIDGE

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continuously monitor the resistance of one resistor on a Brown Recorder. For a 10 C temperature change, we determine the initial hot resistance as that value at which the monitored resistance change reaches minimum, or when 12 minutes have elapsed (for "A" and "B" resistors; 5 minutes for "C" resistors), whichever is greater. For temperature changes larger than 10 C (as in "one-step" tests to be discussed later), only the first criterion is used.

First Step Test On Carbon-Film Resistors

Object. We made our first step-test evaluation on deposited carbon-film resistors of manufacturer "D". Carbon-film resistors, rather than carbon-composition resistors (on which most of our previous work was done), were chosen so that any promise in the method would show up on a "well-behaved" component. All our results up to this time indicated that composition resistors were quite variable at high ambient temperatures.

In evaluating the new procedure, we looked for (1) reduced variability, and (2) reduced testing time. The testing time for step tests is inherently lower than that for the "life-at-temperature" tests. In assessing the variability in ratings, the basic curves of resistance versus time show if all resistors act "pretty much alike". A more precise way of assessing the variability is to define life in some manner and determine whether the life values for the same types of resistor lie close together.

Results. A 1/2-hour lifetime was chosen for the first temperature step test. A preliminary test showed that the temperature range for failure of "D" resistors in a 1/2-hour lifetime would be about 340 to 400 C. The step test was then started at about 325 C (where failures were known not to occur), as shown by the "Temperature" curve, Figure 8. Temperature was stepped by about 10 C every 1/2 hour. The resistances of four groups of three paralleled resistors are shown by the R/R_0 curves, where R_0 is the original resistance at room temperature, and R is the resistance at any time.

In one of the groups, a catastrophic failure occurred on one resistor (it opened up) during the first step, causing the group's resistance value to rise to an R/R_0 of 1.30. All other resistors behaved approximately alike, and, at 360 C, the resistance began to increase steadily during the 1/2-hour lifetime. If a criterion for failure is chosen as a 5 per cent change in resistance during the half hour, one of the groups failed at 360 C and the other two at 370 C.

These results, together with the sudden erratic behavior at 370 C, indicate the promise of the step-test procedure in determining the point of significant deterioration for carbon-film resistors.

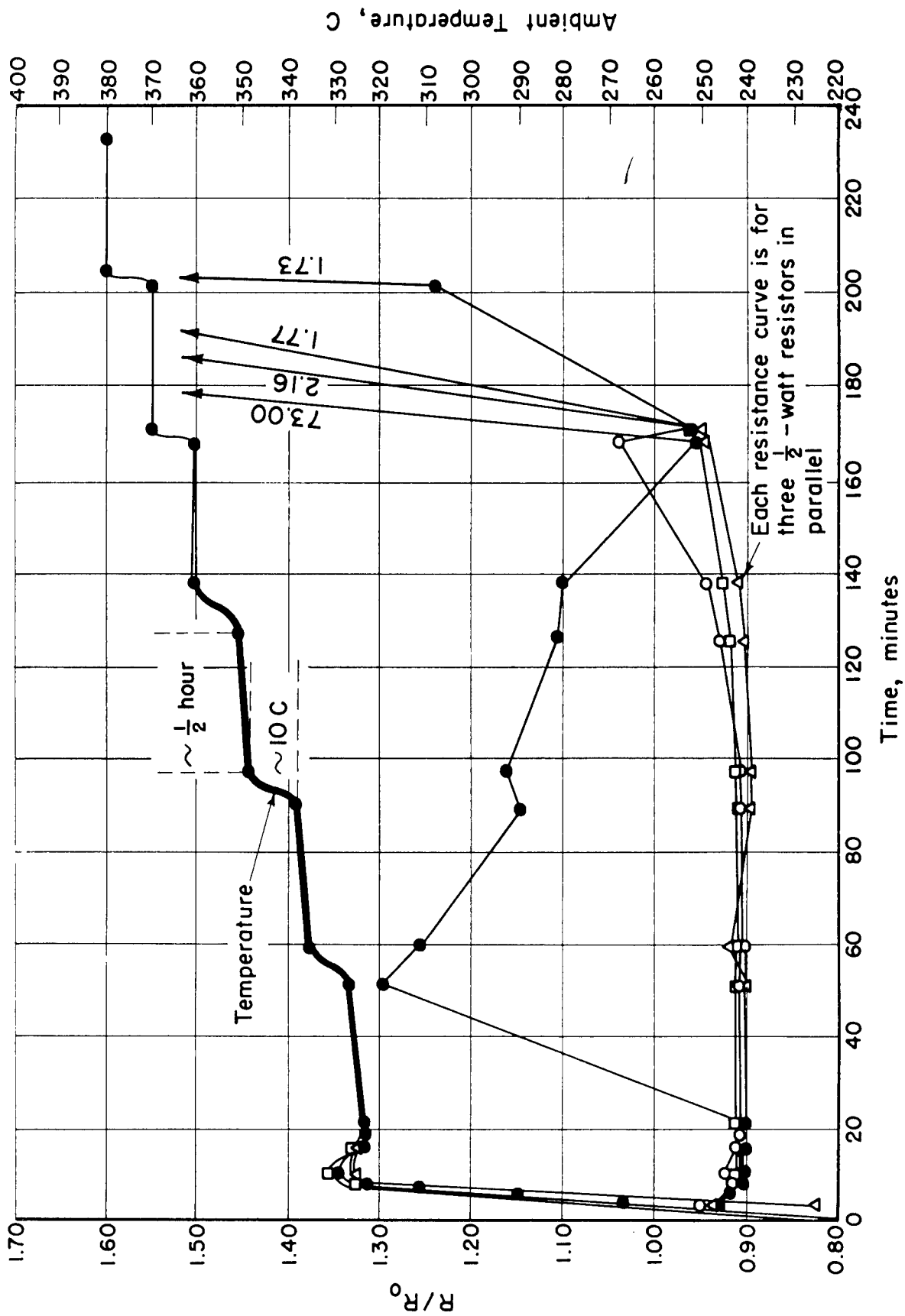


FIGURE 8. THIRTY-MINUTE STEP TEST ON "D" RESISTORS (CARBON FILM)

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Step Tests on Composition Resistors

Object. The results of the step test on carbon-film resistors indicated the promise of the step-test procedure in determining the point at which significant deterioration begins for a "well-behaved" component. We decided that the application of the procedure to rerating composition resistors would be worth investigation.

In the step-test procedure, first tests usually are made at high temperatures and short lives. Knowledge of the component behavior in short tests can be used then to plan the longer life tests efficiently, i. e., the short-life tests indicate the range of temperature to expect for longer lifetimes. Following this plan, we made a 1/4-hour step test on composition resistors. This was followed by 1-hour, 2-hour, and 4-hour step tests, together with "one-step" verification tests. The object of the verification tests is to determine whether the ratings obtained by the short-cut step-test method are the same as might be expected in a practical use of the component (where rise to temperature is probably faster than in the step tests).

15-Minute Lifetime. Results of the 1/4-hour step test are given in Figure 9 for four resistors from each of three manufacturers. If we choose a 5 per cent change of temperature as an indication of failure, failures occurred at 284 C for three of the four "A" resistors. The other "A" resistor failed one step earlier, at 274 C. Three "B" resistors failed at 261 C, the other at 249 C. Results are more variable for "C" resistors. Failures were at 195, 237, 317, and 338 C. The 15-minute test indicated that: (1) no 5 per cent failures would be likely if we started a 1-hour step test at about 240 C, and (2) a 10 C step was small enough not to mask desired information, yet large enough to conserve testing time, at least for preliminary tests.

One-Hour Lifetime. Figure 10 shows the results of two 1-hour step tests for "A" resistors. We made the first step about 240 C, since the 1/4-hour test indicated that no failures would be likely at this temperature. In the lower curve, the resistors were "well behaved" up to the 267 C step. At 267 C, they began to spread apart in resistance; at 278 C, they were "dead" for all practical purposes. Perhaps the best life definition for rating these resistors should give them a 257 C rating. If we define life as the time required for a 2 per cent change in resistance from the initial hot resistance, eleven (out of eleven) resistors fail at 257 C. Failures for a "5 per cent change at temperature" life occurred as follows: two

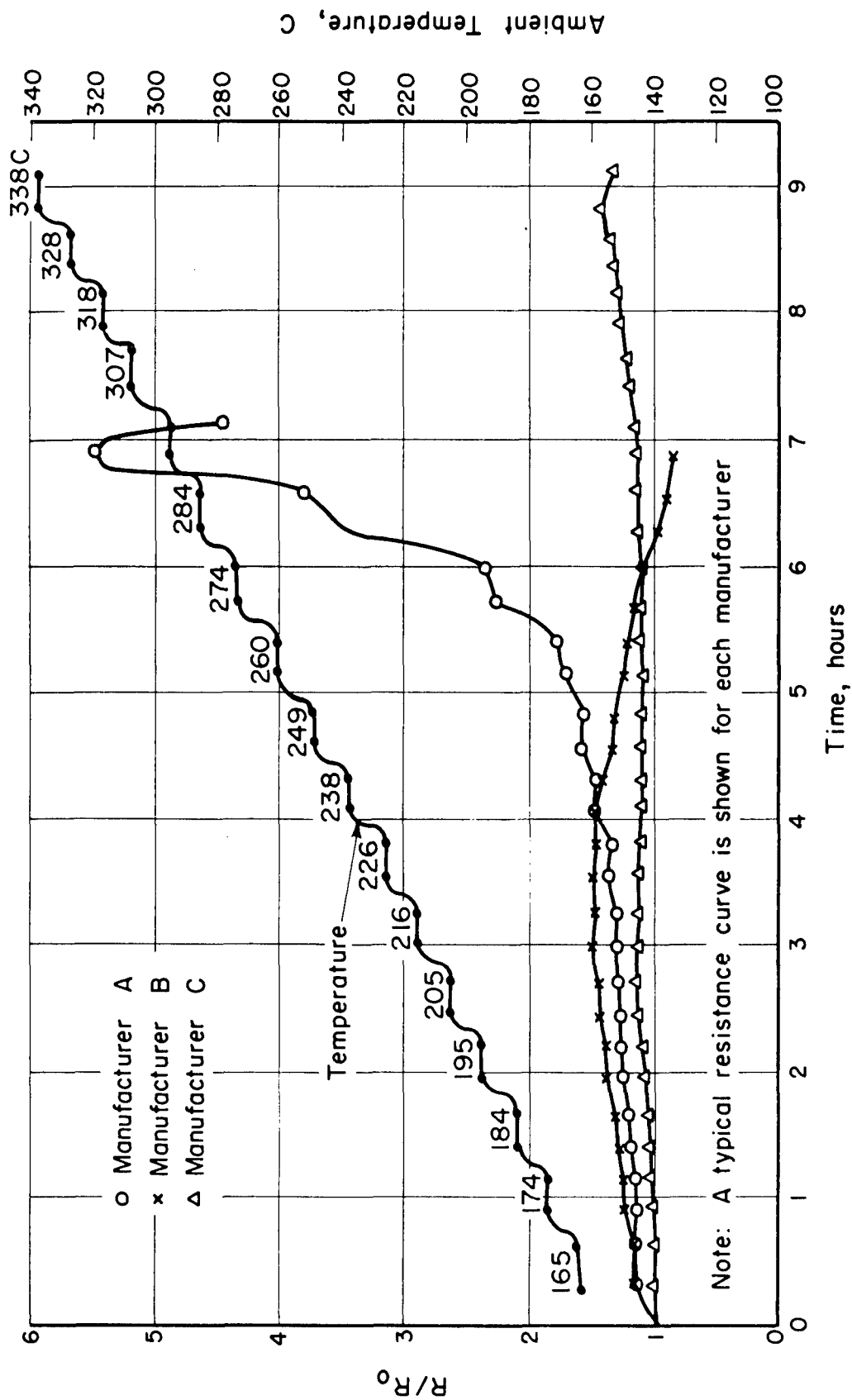


FIGURE 9. FIFTEEN-MINUTE STEP TEST FOR RESISTORS OF THREE MANUFACTURERS

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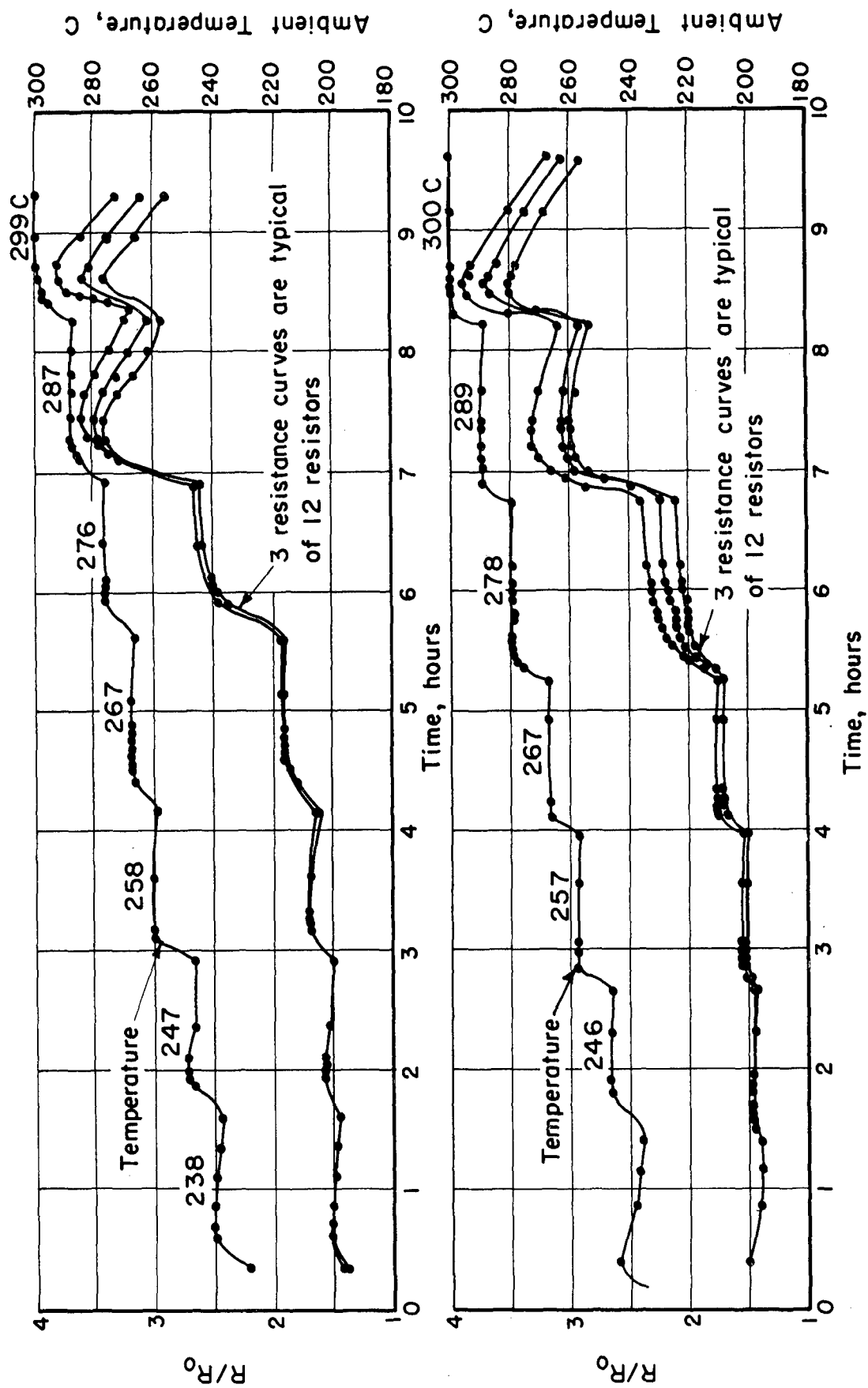


FIGURE 10. ONE-HOUR STEP TESTS ON "A" RESISTORS

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resistors failed at 286 C, nine at 297 C, and one at 276 C. Thus, for this test, the 2 per cent definition gives least variable results from resistor to resistor, as well as giving a failure point that looks more reasonable intuitively than the 5 per cent definition.

If we choose to define a life rating as that temperature at which the resistor exceeds 50 per cent of its original value at room temperature (R/R_0 exceeds 1.5), all the resistors again fail at 257 C. However, such a definition bears no relation to the deterioration of the resistor. An important advantage of the above three definitions is that they determine a lifetime for each individual resistor tested. This type of information lends itself well to statistical treatment.

Life definitions are possible, of course, based on a "group" rating. For example, a life rating which gives a failure point of 257 C means that 257 C is that temperature at which the range ($R_{\max} - R_{\min}$) exceeds 5 per cent of R_{avg} . The possibilities are numerous. Some life definitions which give failure ratings of 267 C mean that, at this temperature: (1) R/R_0 exceeds 1.60 (eleven out of eleven), (2) the range exceeds 10 per cent of R_{avg} , and (3) the range at this temperature increases by 100 per cent from the range at room temperature.

The upper and lower sets of data in Figure 10 show the repeatability of the step-test results, despite nonexact temperature replication. The average failure temperature for a "5 per cent at temperature" life definition for the lower curve is 296 C; that for the upper curve, 278 C. Average initial R/R_0 values for the fourth steps (267 C) are 1.70 and 1.89.

We also found in this test that 10 to 15 minutes are required for an "A" resistor to heat up to the new temperature when the ambient temperature is raised by 10 C. This was determined by continuously monitoring one resistor and defining "rise time" as the time to reach maximum resistance (or minimum resistance change).

Figure 11 shows the results of a 1-hour step test on "C" resistors. A preliminary 1/2-hour-lifetime step test showed that we should start our step test for "C" resistors at a considerably lower temperature than those for "A" resistors, in order to catch all possible failures based on small-percentage "at-temperature" life definitions. The different behavior of "C" resistors compared with "A" resistors is accounted for by difference in construction. A designer, depending, of course, upon application, might call the "C" resistor of Figure 11 unreliable above the 172 C step. If we choose a life definition such that a failure occurs when the resistor exceeds 1 per cent of its initial hot resistance, nine of eleven resistors fail at 172 C. The other two fail at the previous step, 162 C. This definition is "least variable", compared with 2, 3, or 5 per cent definitions for this test.

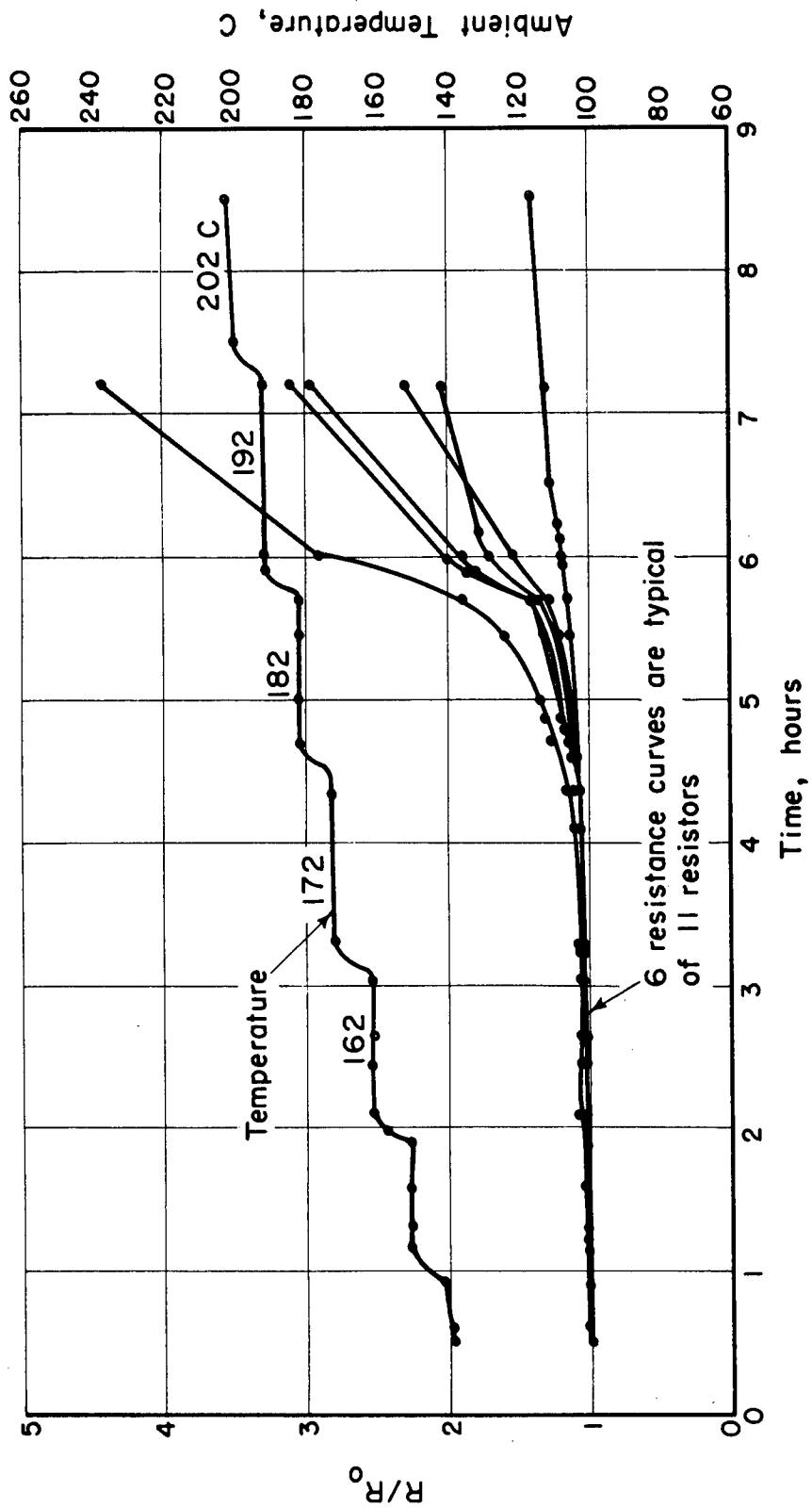


FIGURE 11. ONE-HOUR STEP TEST ON "C" RESISTORS

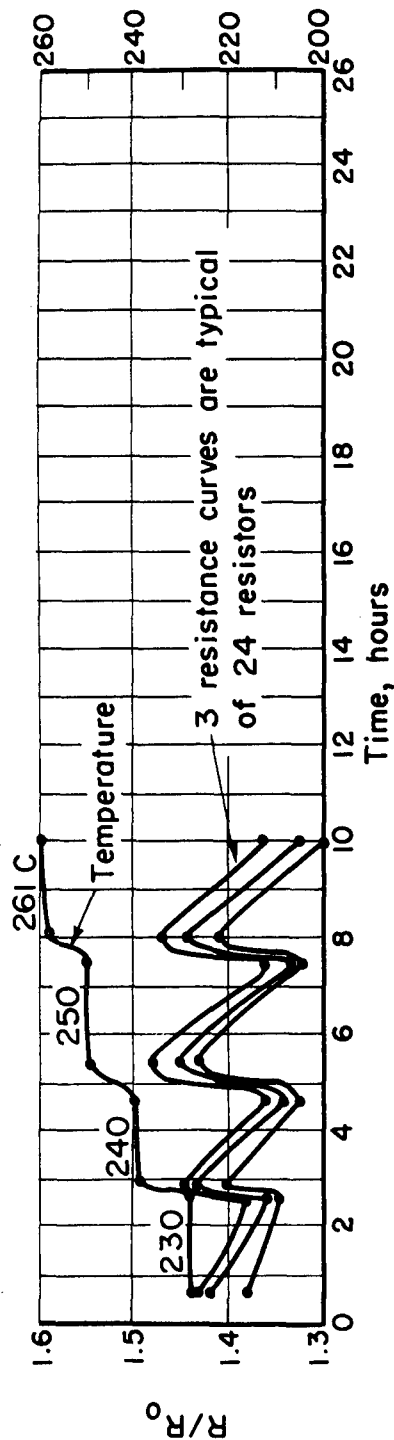
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Figures 10 and 11 for "A" and "C" resistors illustrate the importance of application in defining life (or a life rating). In describing the tests so far, we have emphasized life definitions based on the main characteristic's (resistance) exceeding certain limits while operating abnormally, i. e., when the resistor is hot. Life ratings can be derived by basically different definitions. For example, some existing specifications call for initial measurements at normal conditions, application of the abnormal stress followed by remeasurement under normal conditions. This cycle is repeated, and life can be defined as the total time under stress before failure. However, if no measurements are made under stress, failure must be based on deviations from measurements made under normal conditions at successive intervals. This leads to valid but limited data. For example, a missile designer may wish to know how long a component will last during a 1-shot run. He is much less interested in the number of hours it will last in those instances where the total number of hours is the sum of a number of cycles.

Another possibility in defining "group" life would be to measure the time required for the main characteristic to exceed certain limits around the original normal value. For example, if we obtain ratings from Figure 11 based on a 10 per cent change in average R/R_0 from the original value at room temperature, we get a 192 C temperature rating for "C" resistors. For "A" resistors (Figure 9), using this definition, we get all failures in the first step at 165 C, but with a 5 per cent change at temperature definition, we get ratings of 278 C for "A" (upper curve, Figure 10) and 186 C for "C" resistors (Figure 11). Thus, the "better" resistor depends entirely on the purpose for which it is intended. This suggests that one should not confine his attention in developing rating procedures to one particular definition for all types of resistor. Rather, all types should be rated according to several definitions. On more complicated components, we would expect more definitions to be required. The choice of "one best" life definition is still unresolved. Our choice of a 5 per cent change in the detailed procedure was quite arbitrary.

Two-Hour Lifetime. Figure 12 gives results of two step tests for 2-hour lifetimes. Five per cent failures for 24 resistors occurred as follows: ten at 240 C, seven at 250 C, and seven at 261 C. The lower set of results illustrates 5 per cent failures slightly higher, as follows: seven at 252 C, and eight at 266 C. The other resistors in this test did not fail up to 266 C. Note the poor reproduction of initial R/R_0 values in the upper and lower curves. For example, at 240 C in the upper curve, the initially hot R/R_0 (average) is 1.42. For the lower curve it is 1.35 for the 239 C step. The temperature difference is too small to account for this difference. The difference in R/R_0 values could be due to some cumulative effect in the lower steps of a step test. For the lower set of values, the total elapsed

Ambient Temperature, C



Ambient Temperature, C

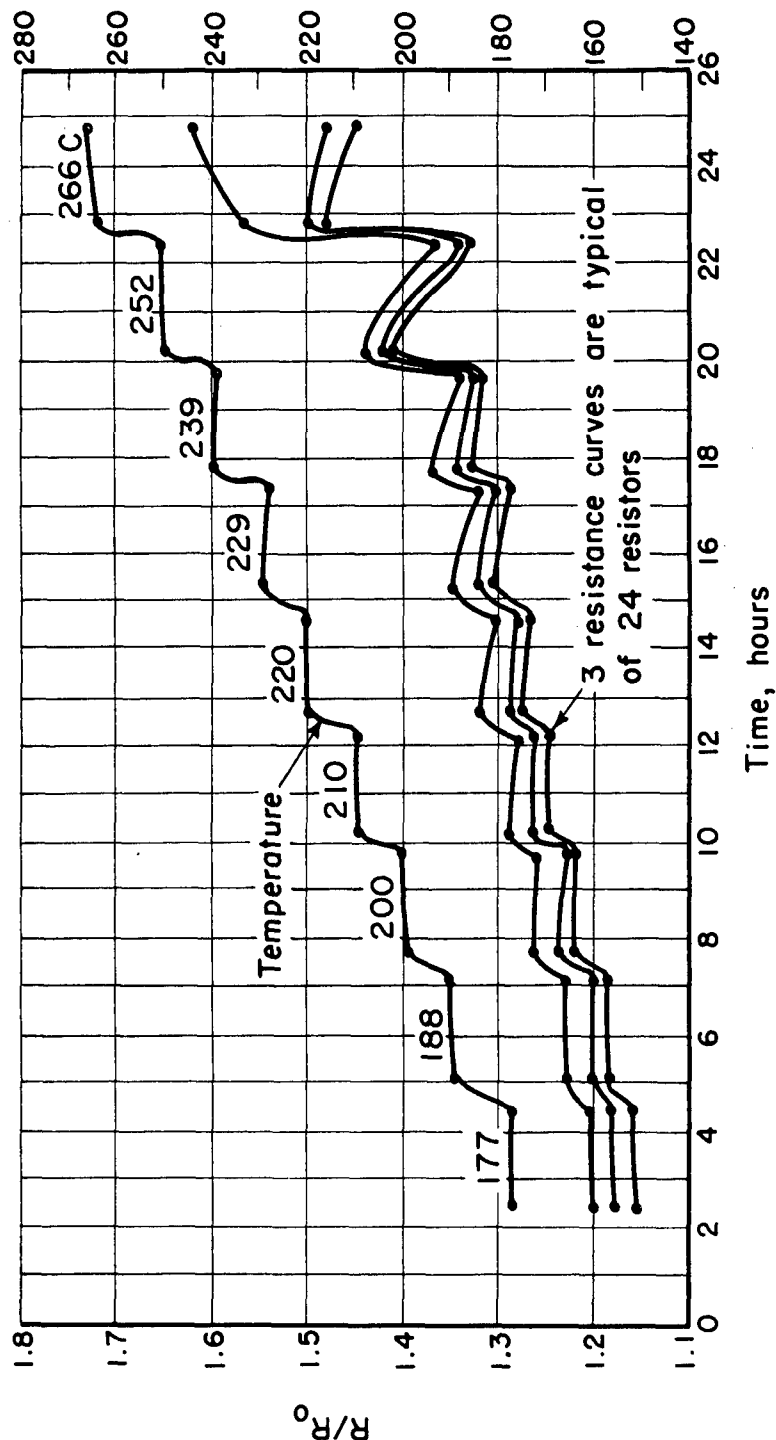


FIGURE 12. TWO-HOUR STEP TEST ON "A" RESISTORS

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time above 170 C is about 15 hours at the beginning of the 229 C step. In the upper set, the total time before the 230 C step is less than an hour. Since higher life ratings (according to "at-temperature" life definitions) are found in the lower set of data, the cumulative effect is beneficial.

These results show the importance of the question, "How do step-test life ratings agree with the expected performance in practical applications?" We made several 2-hour "verification" tests to help answer this question.

One-Step Verification Tests. It is likely that practical applications of resistors would encounter more rapid temperature rises than the step tests. Therefore, we ran several "one-step" tests with comparatively fast rise times to verify the temperature ratings obtained by the step tests. The results of four tests for 2-hour durations are given by Figure 13. In these tests, a new group of resistors is raised rapidly to the desired temperature (the same procedure as used in the Thirteenth Interim Engineering Report); in the step tests, the same resistors are subjected to successively increasing temperatures.

Let us look at 5 per cent ratings to compare step and one-step results for a 1-hour lifetime. Ten (of 12) resistors failed in 1 hour at 276 C for the upper set of test values, Figure 10, and nine (of 12) failed at 300 C for the lower set. In the one-step verification tests of Figure 13, ten resistors failed at 276 C in the first hour. Thus, the step-test ratings are nearly the same or slightly lower than the one-step ratings; then, 1-hour step-test ratings are slightly conservative. Similar results were obtained for lower percentage-change "at-temperature" definitions.

Any ratings based on initial R/R_0 values, however, are not verified, since much higher values are reached by the one-step tests. For example, in the upper curve, Figure 10, R/R_0 values are near 2.4 for 276 C, but in Figure 13, initial R/R_0 values lie between 2.7 and 3.7 for 276 C.

Slightly different results were obtained from the one-step verification tests for the 2-hour lifetime. The average failure temperature for 5 per cent "at-temperature" life for the step tests of Figure 12 is 254 C whereas one-step failures were at 240 C (Figure 13). Thus, step-test ratings for a 2-hour lifetime are slightly optimistic. Agreement of 2-hour-lifetime initial R/R_0 values is not as good as that for the 1-hour-lifetime values.

Four-Hour Lifetime. Figure 14 shows the results of two step tests for a 4-hour lifetime. Repeatability for "at-temperature" ratings was

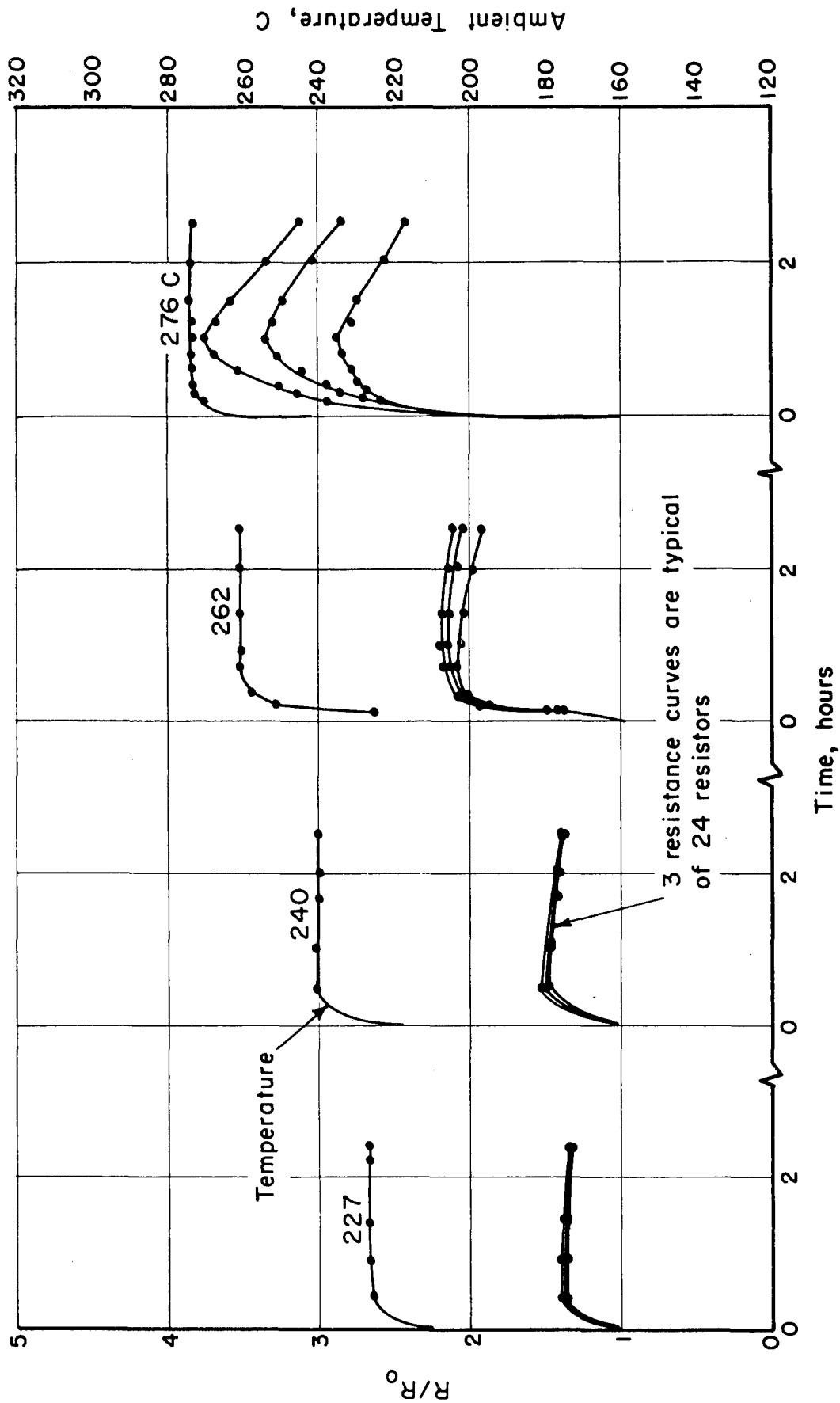


FIGURE 13. TWO-HOUR ONE-STEP TESTS ON "A" RESISTORS

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fairly good. For example, 5 per cent failures for 24 resistors were as follows:

Upper curves: 22 at 255 C; 2 at 266 C.

Lower curves: 8 at 236 C; 4 at 247 C; 12 at 259 C.

Verification tests (Figure 15) in which temperature was reached in one comparatively rapid step gave 5 per cent failures as follows: 3 at 210 C, 12 at 220 C. Thus, step-test ratings are even more optimistic for the 4-hour lifetime than for the shorter periods.

Figure 14 shows another interesting effect. Note the difference in actual R/R_0 values for comparative steps in the upper and lower sets of values. The values lie fairly close together up through the 227 C step (upper) and 230 C (lower) step. The next two steps in the upper curves result in fairly large increases in R/R_0 . The corresponding steps give no appreciable increase in initial R/R_0 values for the lower curves. This may be explained as resulting from accidental deviations from the desired 10 C step. The upper steps from 227 to 240 to 255 C are 14 and 15 C steps. Correspondingly, the lower steps from 230 to 236 to 247 C are only 6 and 11 C steps. Thus, some temperature-shock effect which results in higher resistance values could account for this difference. To determine just how critical this thermal-shock effect is has been the purpose of tests described on page 72.

Life Versus Temperature. Figure 16 shows average temperature ratings obtained from the step tests of Figure 9 through 15 for composition resistors of Manufacturers A and C. Lifetime is plotted as the abscissa since, for the step-test procedure, lifetime is the controlled or independent variable.

The slightly higher ratings for "A" resistors at 1 hour as compared with those at 1/4 hour for the 5 and 10 per cent definitions may be explained by the nature of resistance change for the "A" resistor. Let us look at the upper curve of Figure 10. At the 238, 247, and 258 C steps, the "at-temperature" characteristic is decreasing. At the 267 C step, the characteristic increases slightly, and at 276 C, the characteristic has a definite increase. At 287 C, the characteristic again decreases. This results in failures for resistors that exceed the 5 or 10 per cent limits, both by increasing resistance and decreasing resistance. Two different mechanisms of failure are taking place. The failures at the 1-hour lifetime occurred by decreasing resistance. Some of the failures for the 1/4-hour lifetime occurred by increasing resistance. Although our life definitions are the same, the actual failure mechanisms are different. Thus, the temperature curve increases with lifetime because two different types of life are concerned.

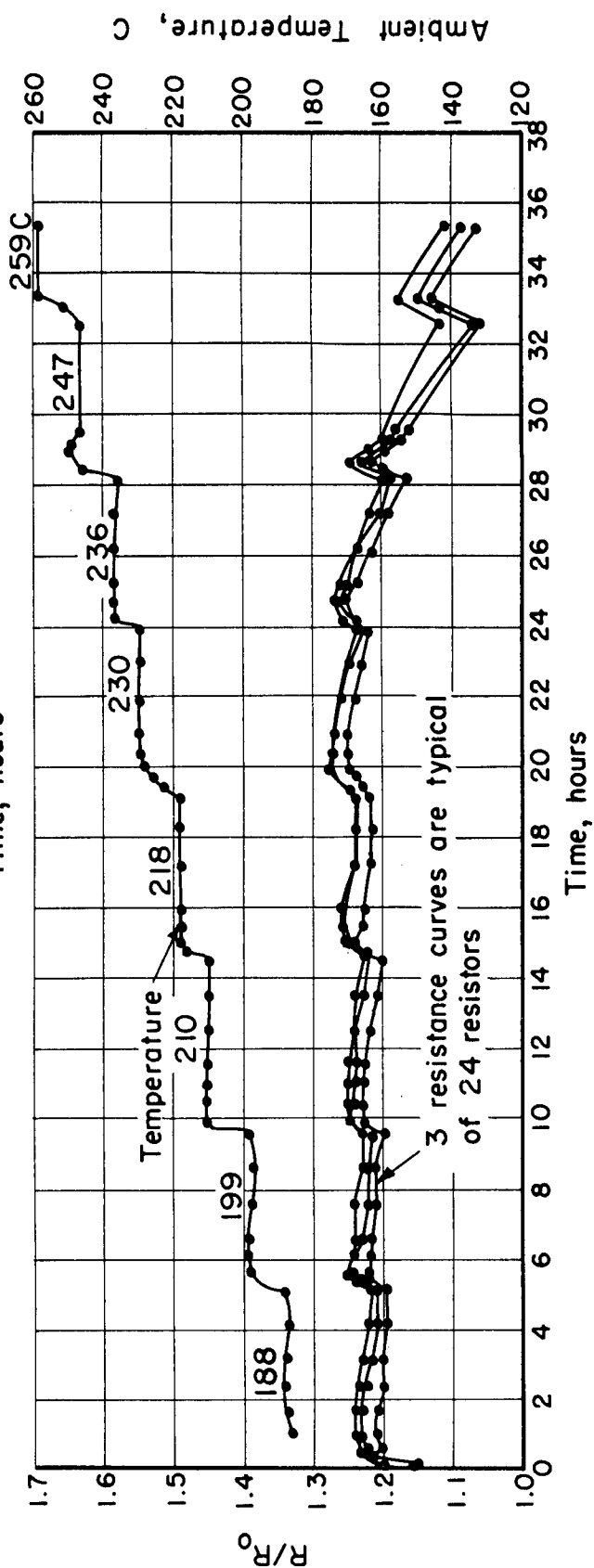
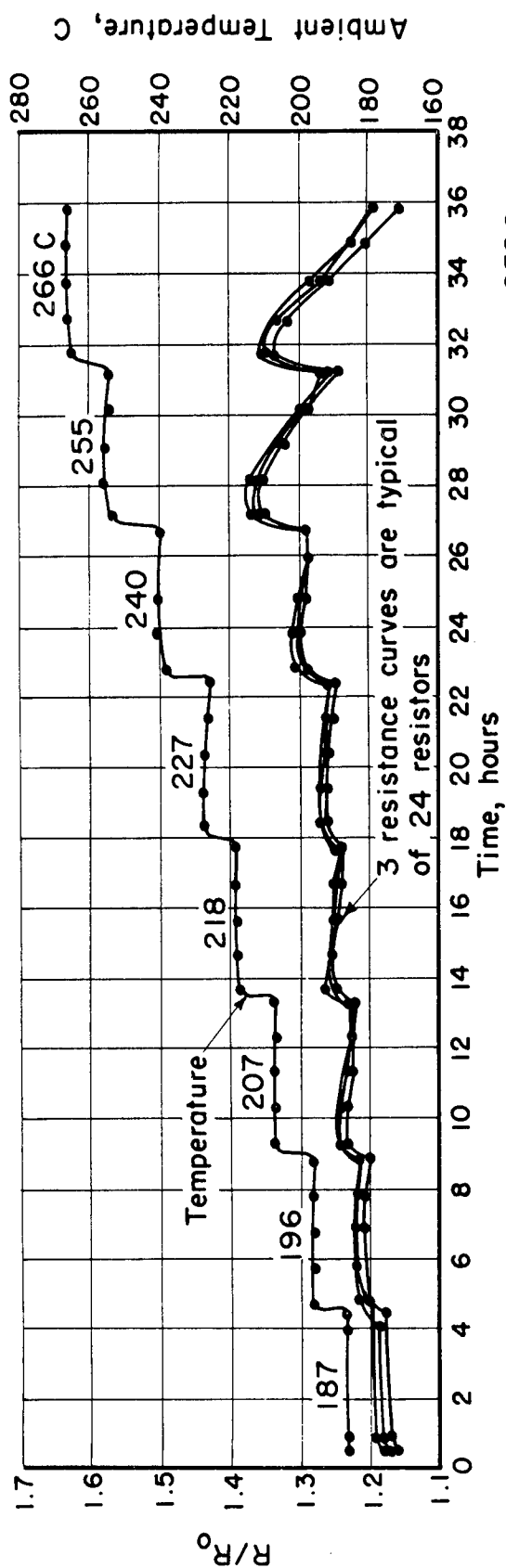


FIGURE 14. FOUR-HOUR STEP TESTS ON "A" RESISTORS

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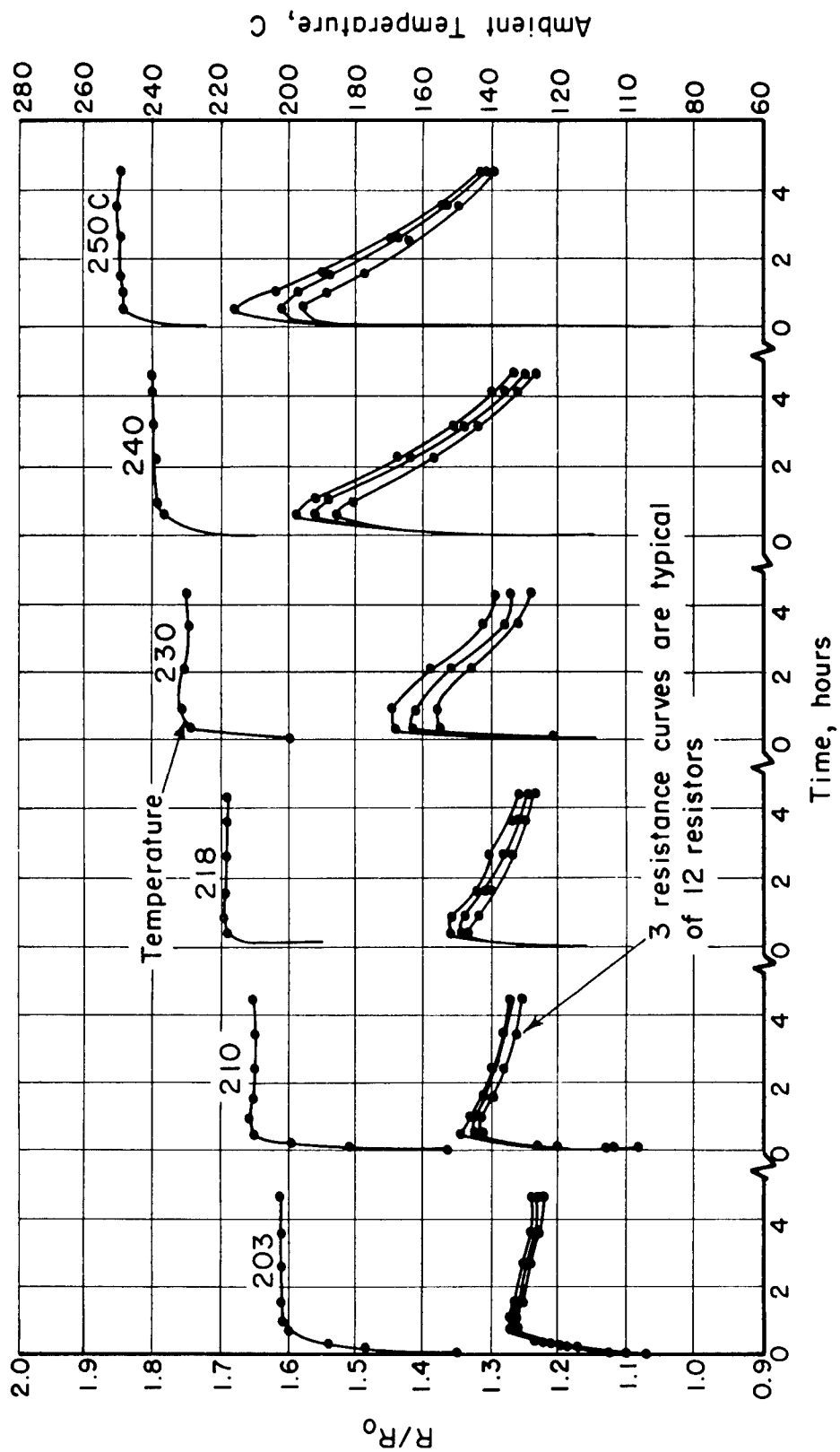


FIGURE 15. FOUR-HOUR ONE-STEP TESTS ON "A" RESISTORS

A-7124

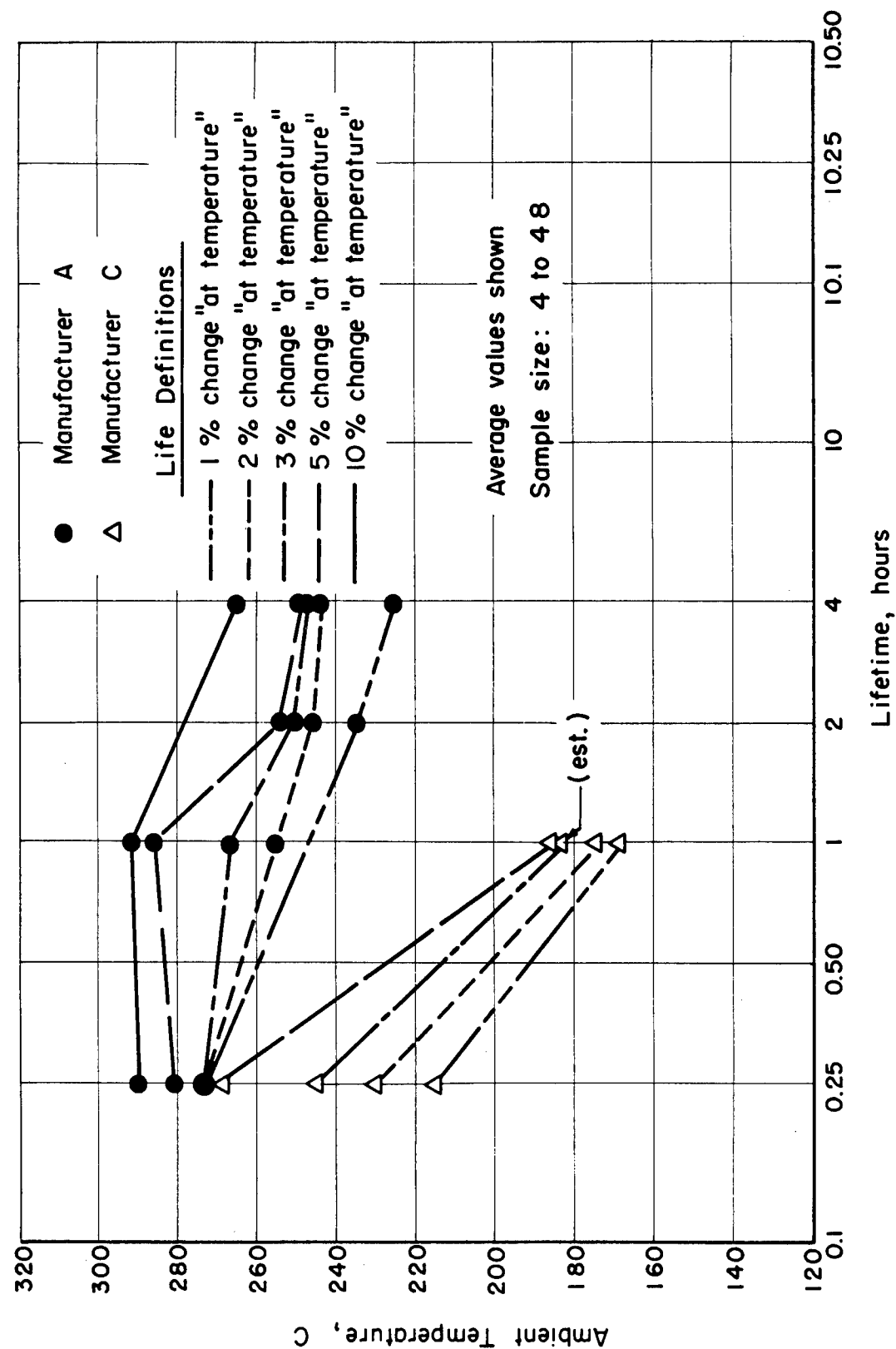


FIGURE 16. TEMPERATURE AS A FUNCTION OF STEP TEST LIFETIME FOR DIFFERENT LIFE DEFINITIONS

A-7125

An analysis of the variability for the different life tests showed that large percentage-change definitions (3 to 10 per cent) give least variable life characteristics for the longer step tests (2- to 4-hour lifetimes). Conversely, small percentage changes (1 to 2 per cent) give least variable life characteristics for the shorter step tests (1/4- to 1-hour lifetime).

Conclusions

The stress-step method of life testing produces less variability in lifetimes than the "life-at-temperature" procedure described on page 43. The stress-step method produces overly optimistic ratings for lifetimes much longer than 2 hours. (As lifetime becomes longer, the ratings become more optimistic.)

A 1-hour stress-step test appears to be a powerful method for obtaining fast order-of-magnitude answers to make further life tests more efficient. Essentially, this means that the 1-hour stress-step method is a shortcut to estimating the temperature range necessary to study a given lifetime range. One-hour stress-step tests have been incorporated into the life-rating procedure for this purpose.

Reduced variability was obtained in 1-hour stress-step tests by using a 1 or 2 per cent change definition of life (rather than 5 per cent). The advantage does not appear sufficient to overcome the disadvantage of requiring more accurate resistance measurements.

Cycling Step Tests

There are many procedures which can be written to determine life ratings. Another procedure which appeared worthy of experimental investigation was a procedure combining temperature cycling with step testing. The equipment used has been described in the previous section. The results in Figure 17 are for 1-hour lifetimes for resistors from three manufacturers. Here, temperature is again stepped by 10 C and held at each step for the 1-hour lifetime. Between steps, the resistors are returned to room temperature for not less than 1 hour. Figure 18 shows the results of a similar test on "A" resistors for a 4-hour "at-temperature" lifetime.

Several ways of obtaining temperature ratings for the given lifetime are possible for the cycling procedure. Table 3 shows ratings obtained from Figures 17 and 18 by two methods. The first method (for the column headed "Rating Measured at Room Temperature") is:

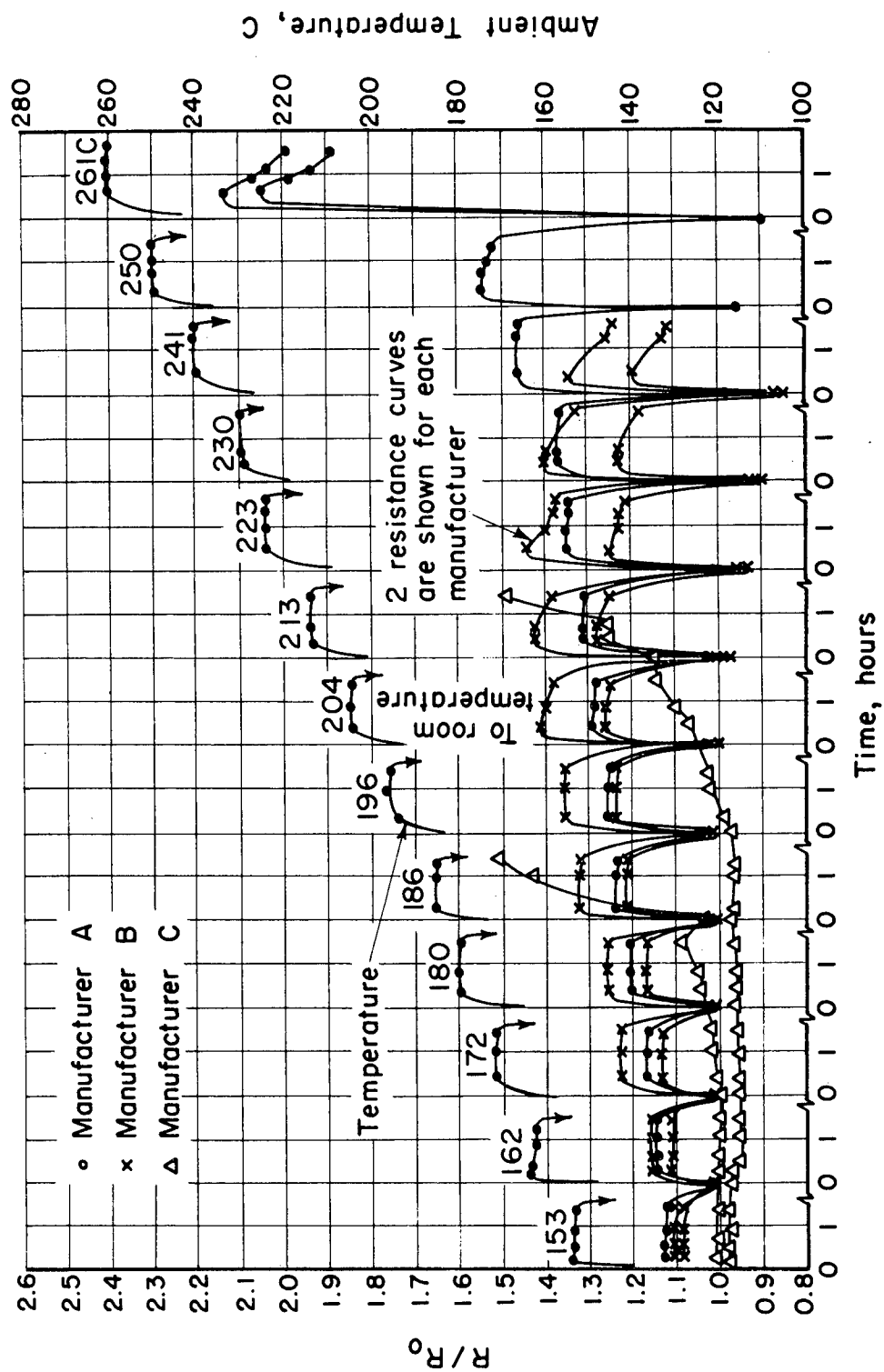


FIGURE 17. ONE-HOUR CYCLING STEP TEST FOR RESISTORS FROM THREE MANUFACTURERS

A-7126

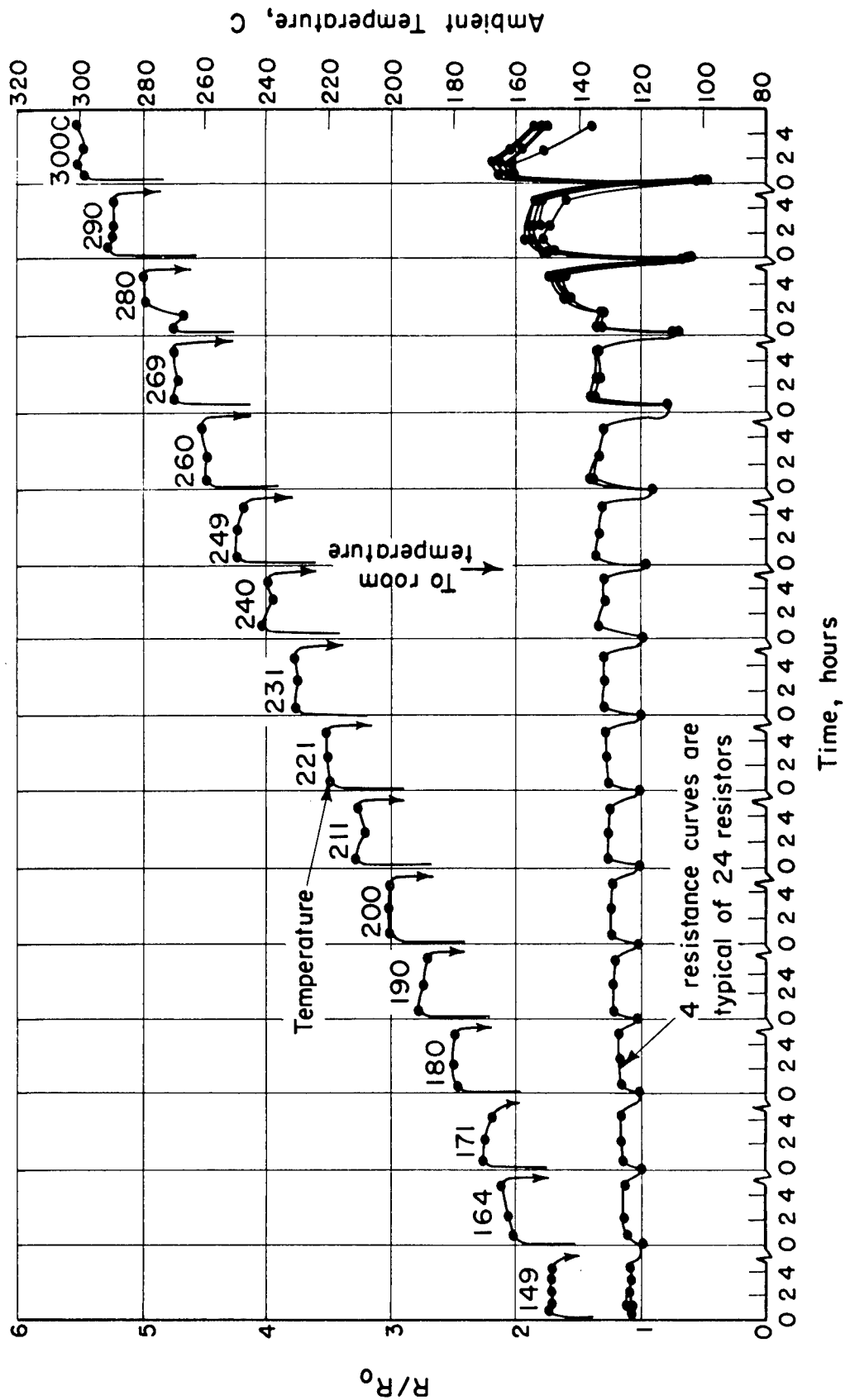


FIGURE 18. FOUR-HOUR CYCLING STEP TEST ON A RESISTORS

A-7127

TABLE 3. TEMPERATURE RATINGS OF COMPOSITION
RESISTORS OBTAINED BY CYCLING

Per Cent Change	Manufacturer:	Rating Measured at Hot Tem- perature, C			Rating Measured at Room Tem- perature, C		
		A	B	C	A	B	C
<u>One-Hour Lifetime</u>							
1		254	196	179	153	153	166
2		261	206	190	153	175	171
3		---	227	190	169	192	178
5		---	236	192	250	205	189
<u>Four-Hour Lifetime</u>							
1		186			151		
2		217			151		
3		231			156		
5		259			199		
10		276			254		

- (1) For each resistor, calculate percentage change from the initial resistance at room temperature to the resistance at room temperature after each temperature cycle.
- (2) Assign as the temperature of failure the temperature of the cycle immediately preceding the point where at least 1 per cent (for the first row) change has occurred.

For the column headed "Rating Measured at Hot Temperature", the procedure is:

- (1) For each resistor calculate the percentage change from the initial hot resistance to the final hot resistance.
- (2) Assign as the temperature of failure for each resistor the temperature of the cycle where greater than 1 per cent (for first row) change occurs.

The different rows in Table 3 are for different per cent changes used in the life definition. Values in Table 3 are average temperature ratings for 8 to 24 resistors.

Table 3 shows some interesting results:

- (1) Temperature ratings based on room-temperature measurements are lower than ratings based on "hot"-temperature measurements.
- (2) The cycling step tests gave higher temperature ratings than the step tests for the 1-hour lifetime. (Compare average-temperature ratings in the column, "Rating Measured at Hot Temperature", Table 3, with the 1-hour value in Figure 16.)
- (3) The cycling step tests gave lower temperature ratings than the step tests for the 1, 2, and 3 per cent 4-hour life definitions. The reverse is true for the 5 and 10 per cent life definitions. (Compare the last half of Table 3 with Figure 16.)

Conclusions

Cycling tests have the advantage that life definitions may be based on measurements at either room or "hot" conditions. The use of test procedures based only on room-temperature measurements would clearly be economical. Test results indicate that this may be feasible; however, such procedures could be justified only by a much larger amount of corroborating evidence.

Test results indicate that the limitation in the cycling-step procedure chosen here is related to the limitation which has been shown for step tests alone, i.e., overly optimistic ratings occur for certain conditions. (Items (2) and (3) above show that some of the ratings are even more optimistic than those obtained from the straight step tests.) These overly optimistic ratings occur, of course, simply because the life characteristic of the resistors is modified in some way (perhaps by curing or drying) in the early stages in the test.

Conditioning of Carbon Resistors

The elimination of any uncontrolled variable in testing is an aim which hardly can be questioned from a theoretical point of view. The elimination

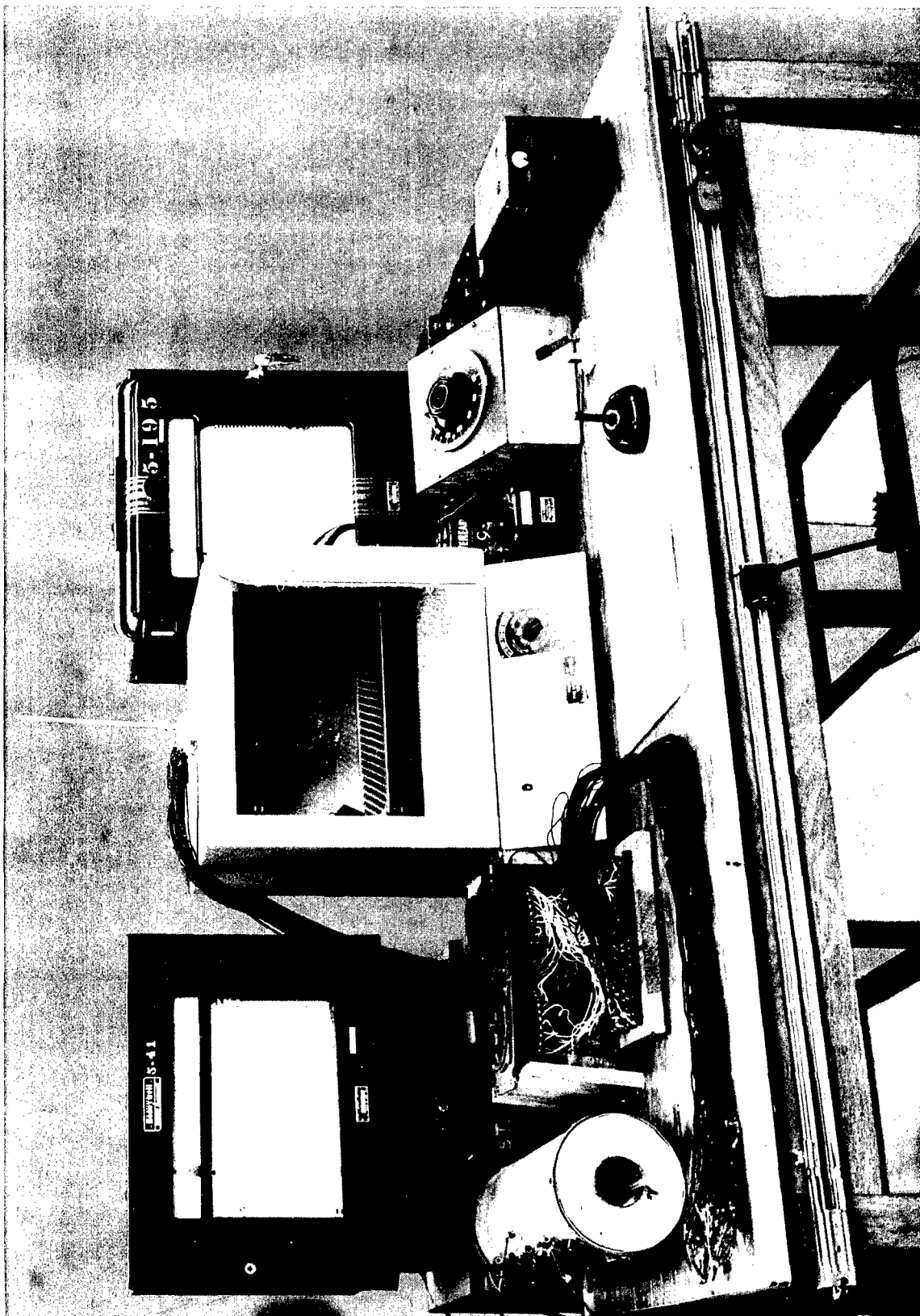
of the moisture in resistors prior to testing is in line with this objective. As a practical matter, however, work reported in the Supplement to the Thirteenth Interim Engineering Report showed that "life variability has not been reduced significantly" by either 50 C or 100 C preconditioning for 100 hours. It was observed, however, that 100 C preconditioning caused much longer lifetimes than no conditioning.

The reason for the occurrence of this effect on only one manufacturer's resistors was unknown. Another unanswered question was, "If a conditioning procedure should be specified in the rating procedure, what should it be?" Obviously, any conditioning in a test procedure should be confined to moisture removal from the resistor and should not otherwise improve the resistor (by curing of resins, for example). Different manufacturers offered contradictory suggestions when consulted on these problems, so experimental conditioning was undertaken to supplement information leading to intelligent selection of a conditioning procedure.

The following test was run to study conditioning effects. Ten-kilohm and 100-kilohm resistors from two different manufacturers were divided numerically into three equal groups. One group received no initial treatment. The second was dried 100 hours at 50 C. The third was dried 100 hours at 100 C. After this, the three groups were exposed to moisture for 250 hours at 52 C and 100 per cent relative humidity. Resistors were measured before and after moisture exposure. Each group of resistors was then divided into two groups, one of which was conditioned at 50 C for 100 hours, the other at 100 C for 100 hours. Resistors were measured periodically during conditioning. The basic sample size of the smallest subgroup was four resistors. Drying ovens and associated equipment are shown in Figure 19.

Figure 20 shows the results on resistors manufactured by "A" company. These resistors are molded solid compacts of carbon and insulating binder with a "bakelite"-type covering. No wax coating was present. The curves shown are for typical resistors; there was no essential deviation in the shape of these curves for any of the resistors measured, regardless of the treatment given before exposure to moisture. The ordinate shows the ratio of resistance measured at the time indicated on the abscissa to the resistance measured before exposure to moisture. Exposure to moisture caused the 10-kilohm resistors to increase about 5.5 per cent in value, and the 100-kilohm resistors about 7 per cent.

Measurements at room temperature are indicated by the large circles; measurements at conditioning temperatures are indicated by small dots. At the zero time indicated on the abscissa, the resistors were placed in ovens, some at 50 C and some of them at 100 C. At 100 C, the temperature



91605

FIGURE 19. EQUIPMENT FOR CONDITIONING TESTS

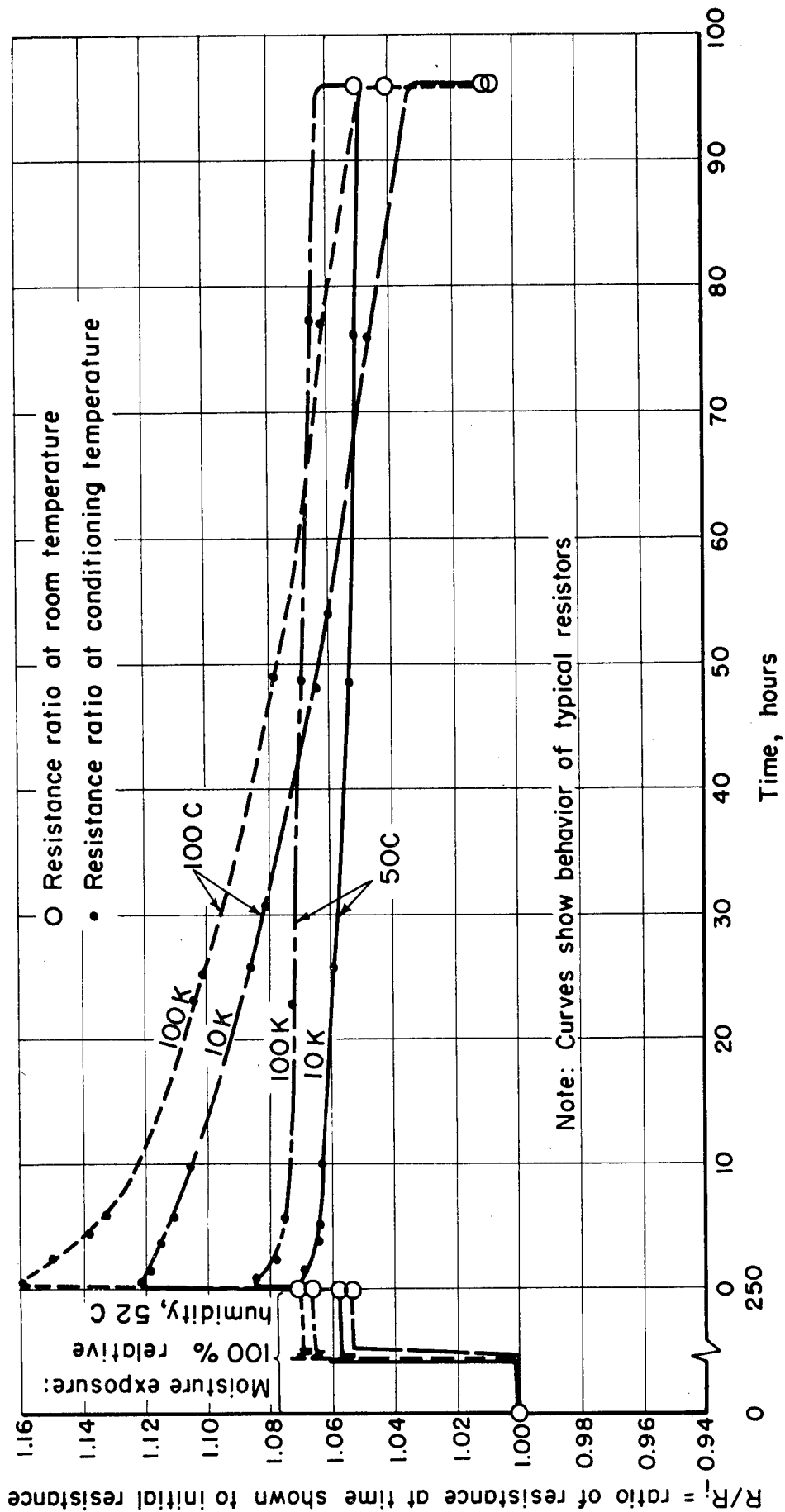


FIGURE 20. 50C AND 100C CONDITIONING OF 10-KILOHM AND 100-KILOHM COMPOSITION RESISTORS
A-7128

increase in resistance of the 100-kilohm resistors was approximately 15 per cent above the original value. The 10-kilohm resistors increased to approximately 12 per cent above the original value. After a first rapid decrease and then a moderately slow decrease over the whole period of 100 hours, the 100 C conditioning returned the room-temperature values of both the 10-kilohm and 100-kilohm resistors to within 1 per cent of the initial value before exposure to moisture. The 50 C conditioning, on the other hand, produced little change in the resistance value, even after 100 hours at that temperature. In fact, the total decrease in resistance due to moisture removed at 50 C conditioning was only about 1 per cent for the 10-kilohm and the 100-kilohm resistors.

However, the resistors which were held at 100 C were still decreasing at a steady rate, even after 96 hours, and the question of what happens then, and whether it can be attributed to simply moisture removal, rather than to continuous curing of the resin, is one that must be answered. In an attempt to find an answer to this question, several of these same resistors were re-exposed to moisture for a period of 250 hours at 100 per cent relative humidity and 52 C (see Figure 21). The moisture had approximately the same effect again on all resistors, causing an increase in resistance this time of about 3 to 5 per cent. At zero time, the resistors were again placed in an oven at 100 C. This time they were held at this temperature for a period of 400 hours, and resistance measurements were made at several intervals during that time. The behavior during the first 100 hours was very similar to that shown in Figure 20. This period of time in the oven caused the resistors to decrease by approximately 14 per cent. The next 300 hours, even though showing a steady decrease, showed a decrease of only 3 per cent during the whole 300 hours. These results are shown in Figure 21. We can conclude, therefore, that most of the effect of the 100 C temperature can be attributed to a moisture-removal effect, at least for this manufacturer's resistor.

How Do Other Manufacturers' Resistors Respond to Conditioning Treatment? Figure 22 shows the effect of 50 C conditioning on Manufacturer C's composition resistors. These composition resistors are of the carbonaceous-ink type, protected by a bakelite coating. Here, it is obvious that the reaction to conditioning is dependent, at least in part, on the past history of the resistor. The central curves show that, on exposure to moisture, a very small change occurs - on the order of 0.5 to 1.5 per cent. These central curves are for resistors which had been subjected to 50 C or to no conditioning at all before exposure to moisture. The 50 C conditioning apparently has a small effect during the first 5 hours at temperature. At the end of 100 hours, the resistors return to within about 0.5 per cent of their value before exposure to conditioning. The upper and lower curves are

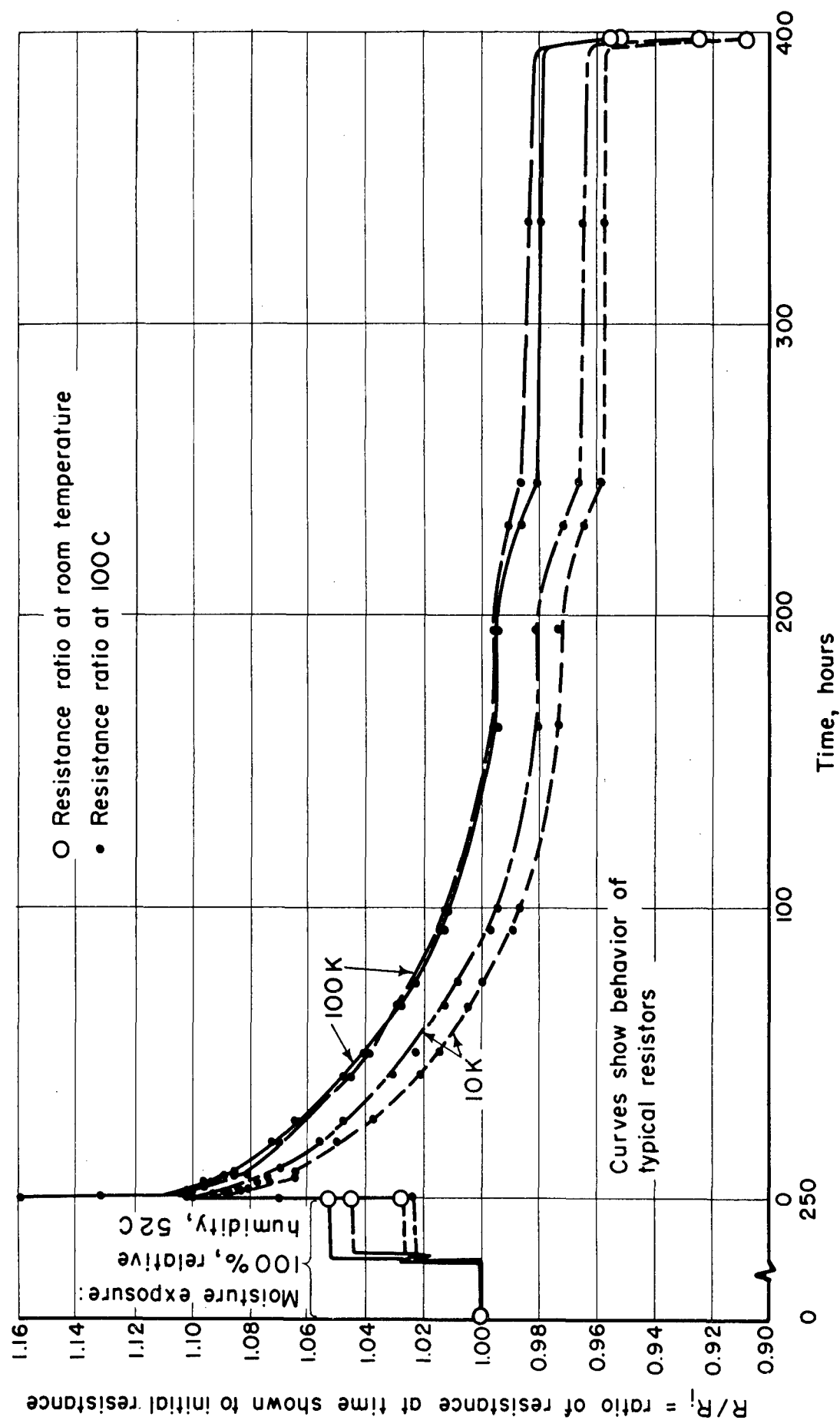


FIGURE 21. EXTENDED 100°C CONDITIONING OF 10-KILOHM AND 100-KILOHM COMPOSITION RESISTORS OF MANUFACTURER A

A-7129

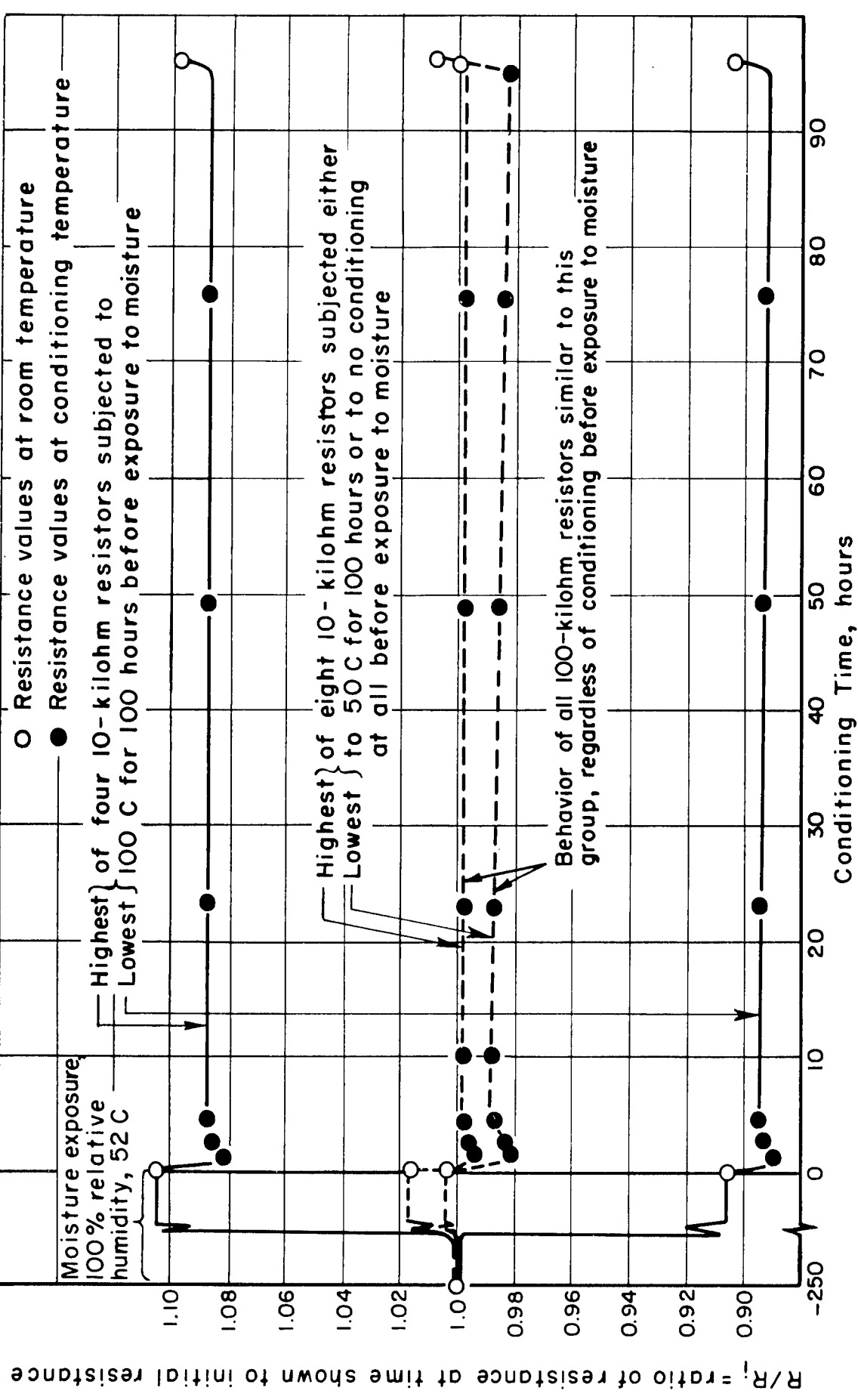


FIGURE 22. 50 C CONDITIONING OF 10-KILOHM AND 100-KILOHM COMPOSITION RESISTORS
OF MANUFACTURER C WITH VARIOUS PAST HISTORIES

A-7130

for resistors which have been subjected to 100 C for 100 hours before exposure to moisture. It becomes evident that the effect of the moisture is quite pronounced on these resistors, being of the order of plus or minus 10 per cent. The 50 C conditioning thereafter, however, produced very little change in the resistors. On these resistors, moisture seems to cause a permanent change which 50 C conditioning has little effect on. A conditioning temperature before exposure to moisture of 50 C or lower has no influence on the behavior of the resistors. Conditioning of 100 C, however, probably weakens the wax coating and makes the resistors more susceptible to moisture.

Figure 23 shows the effect of 100 C conditioning on Manufacturer C's composition resistors. Here again, the past history has an obvious and important effect on at least the 10-kilohm resistors, although it seemed to have little effect on the 100-kilohm resistors. The behavior is similar to that shown in Figure 22 for the 50 C conditioning treatment, that is, at the end of 96 hours, they returned to the same value of resistance as that at the initial exposure to the 100 C conditioning. The 10-kilohm resistors, on the other hand, seemed to have experienced a small, permanent negative set in room-temperature value after 96 hours at 100 C. It is difficult to understand how the wax-coating effect could explain the behavior of the 10-kilohm resistors and not have any appreciable influence on the 100-kilohm resistors; hence, there may be some other unexplained influence at work.

Figure 24 shows the effect of conditioning on deposited-carbon-film-type resistors. These resistors have a varnish coating. The moisture tends to have some effect on the carbon-film resistors in spite of the varnish coating; the effect seems to be that of a permanent set which is not removable by later conditioning. Treatment prior to exposure to moisture (past history) has no significant effect on the results obtained.

Conclusions

Conditioning produces different effects on different types of composition resistors. Conditioning must be prescribed in the test procedures, so that resistors will not be rated incorrectly.

A conditioning period of 100 hours at 105 ± 5 C has been specified in the life-rating procedure given in this report. The procedure also specifies that ratings be obtained on resistors which have been exposed to moisture; this will allow assessment of the importance of the condition of resistors when speaking of their life rating. Moreover, it is recommended that any coatings present be stressed at the highest likely short-term temperature rating before exposure to moisture.

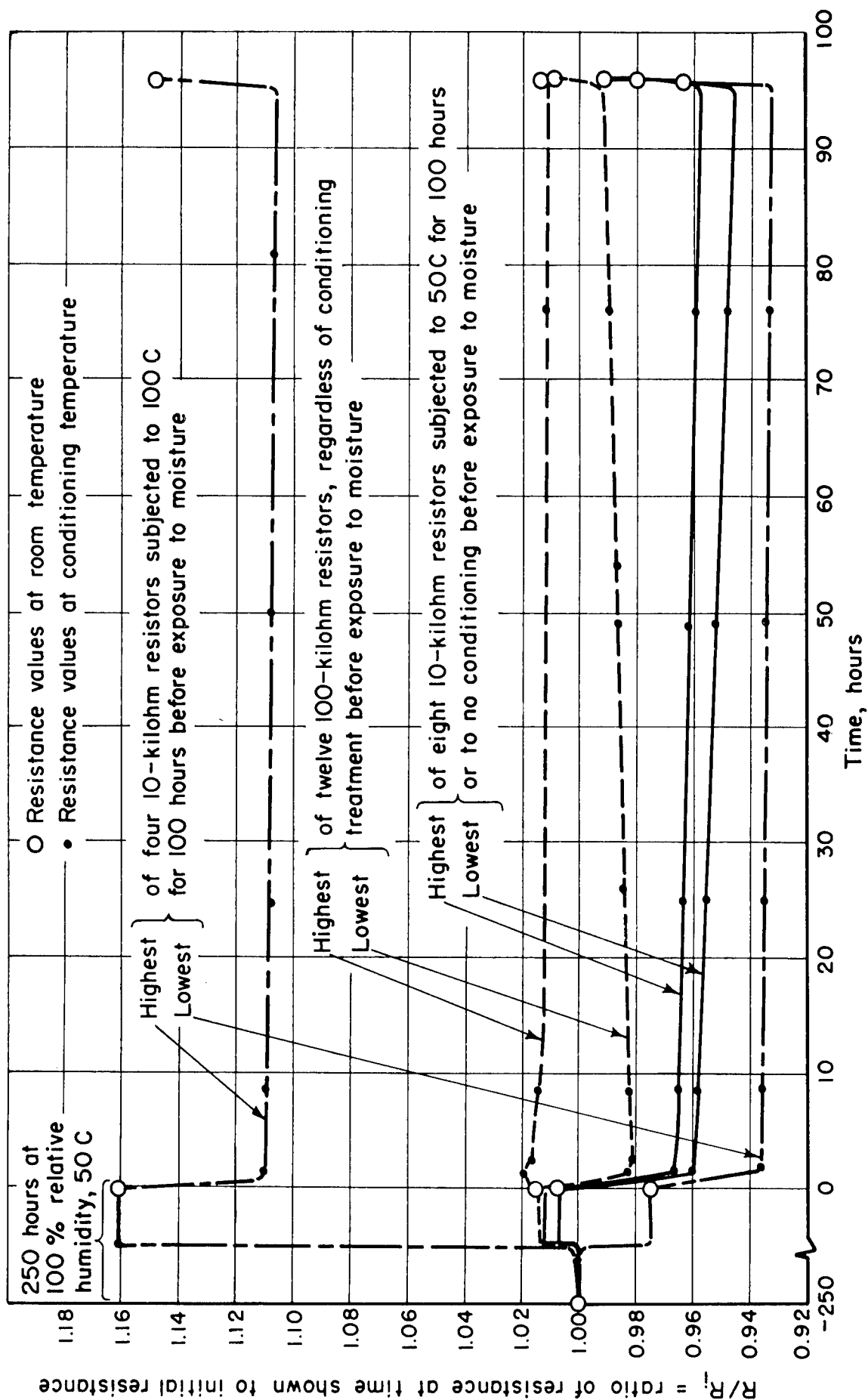
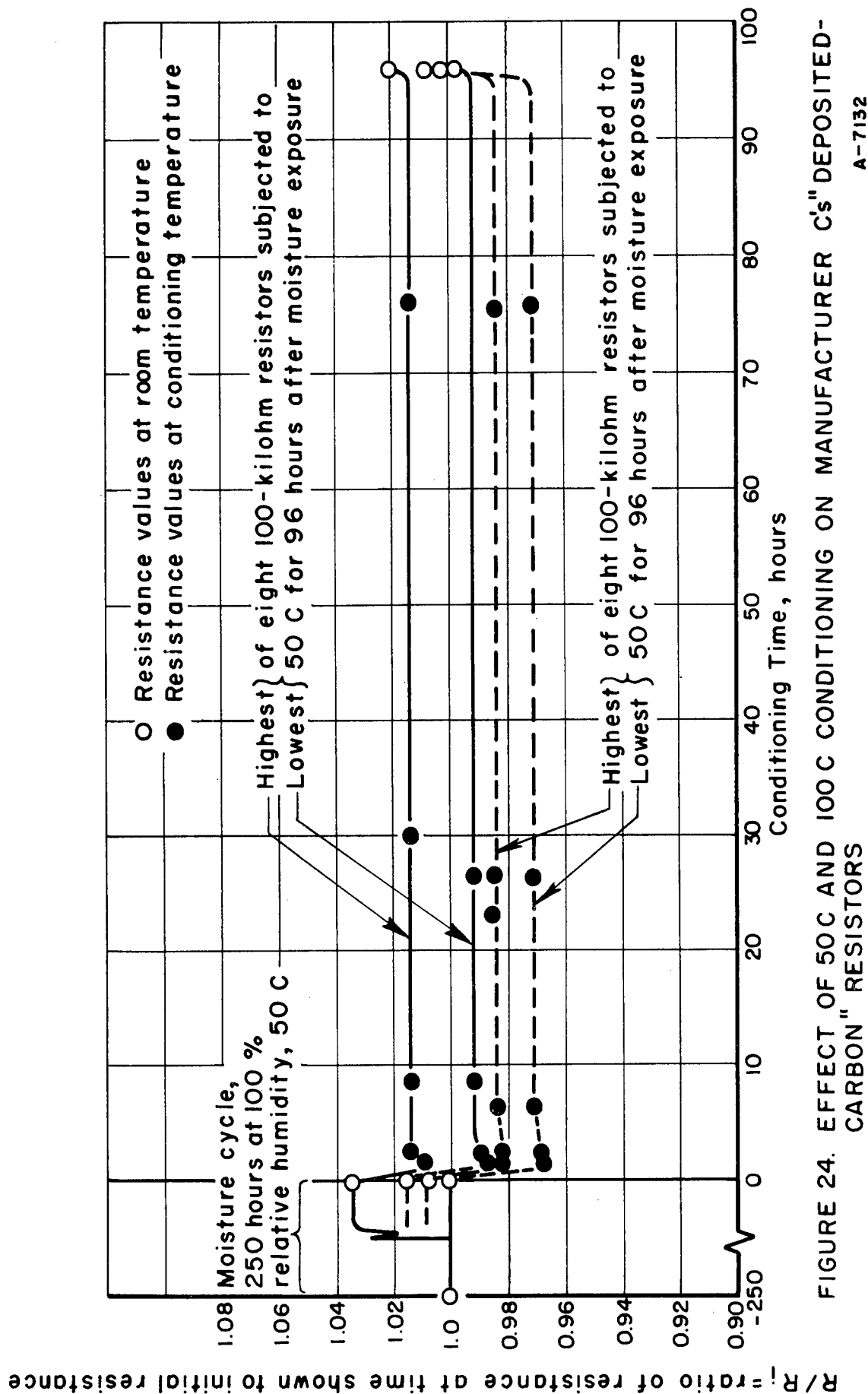


FIGURE 23. 100°C CONDITIONING OF 10-KILOHM AND 100-KILOHM COMPOSITION RESISTORS OF MANUFACTURER C WITH VARIOUS PAST HISTORIES A-7131



Noise of Composition Resistors

Purpose

The purpose of noise measurements was to determine how important noise is in re-rating composition resistors at high ambient temperatures.

Some applications call for low noise levels. It is obvious that life ratings are meaningless for these special applications unless the maximum noise level is specified. Rather than merely specifying a maximum noise level, the possibility of defining life as the time required to reach a critical noise level should also be considered. If noise is an important limiting factor in the temperature range under consideration, a standard noise-measuring technique must be established.

Circuit

Quantitative measurements were made of the thermal noise of composition resistors with the circuit of Figure 25. The upper diagram shows the circuit used for noise measurements. R_s and R_s' are wire-wound resistors used as low-noise standards. R is the resistor under test. The lower diagram gives the calibrating circuit. With the switch in Position 1, a signal level is established. With the switch in Position 2, the oscilloscope gain is adjusted for the desired calibration in microvolts per inch. Stray pickup was kept to a minimum by careful shielding. The resistor under test, R , and the leads to R in the oven were shielded. The external circuit was shielded with an aluminum lard can, and shielded leads to the oscilloscope were used.

Results

The average noise for several resistors was found to be less than 1 microvolt per volt up to 250 C over a 4-hour period. Noise tests up to 400 C showed that the noise settles down to some value less than 1 microvolt per volt a few minutes after temperature is reached. During rapid rise to these temperatures, the noise gets as high as 8 microvolts per volt. On rapid cooling, it may be as high as 20 microvolts per volt. The behaviors of three makes of carbon-composition resistors were approximately the same.

Conclusions

These results indicate that thermal noise is not a limiting factor in rating composition resistors at high ambient temperatures. Further testing is needed to establish this conclusively.

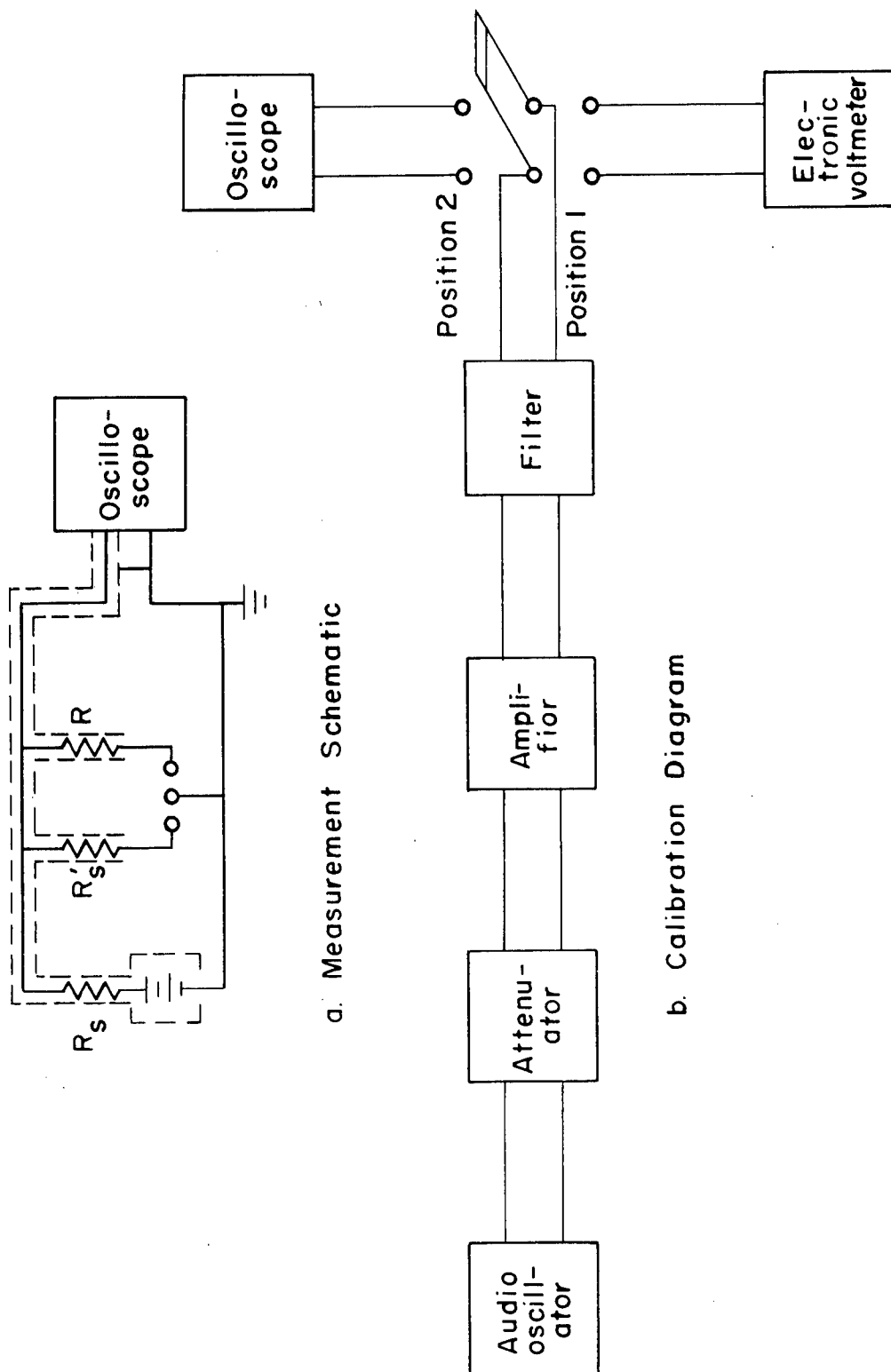


FIGURE 25 NOISE - MEASURING CIRCUITS

A-7133

Resistance-Temperature Characteristic

We have mentioned that the life rating of a resistor should be determined as the time required for given percentage changes while the resistor is actually deteriorating. The temperature coefficient of a resistor is a reversible change and, hence, should not be included in the life definition.

In a practical application, however, the actual beginning resistance value at a given temperature is usually of importance.

Figure 26 shows such a characteristic for "A" resistors under no load.

The ratio R_i/R_o is the initial hot resistance divided by the original resistance at room temperature. Each point on this curve is an average determined from different tests in which different groups of resistors were raised to the given ambient temperature. Sample size varied from 11 to 24. Ninety-five per cent confidence limits for each point are too narrow to be shown for the scale used in Figure 26. For example, the widest limits are for the point at 275 C. They are 0.03 on a mean R_i/R_o of 3.01. It should be noted that these confidence limits apply to a population of "A" resistors of the same type, but can be expected to be valid only for exact reproduction of experimental conditions. Since the slope of the R_i/R_o curve is very steep in this portion of the curve, any slight rise-time or temperature-overshoot variation in the method might result in an R_i/R_o ratio outside of these limits.

Conclusions

The resistance-temperature characteristic appears to be usefully predictable for "A" resistors. The life-rating test procedure specifies that resistance-temperature-characteristic data be obtained from the life tests which are specified. The data are readily available, and no special tests are necessary.

Rise-Time Tests

Purpose

Many of our life tests on composition resistors indicated that the life values obtained could depend critically on the "rise time" to the test temperature. It was logical to suspect that some thermal-shock effect in rapid heating could deteriorate the resistor more than a gradual, carefully controlled heating-up period.

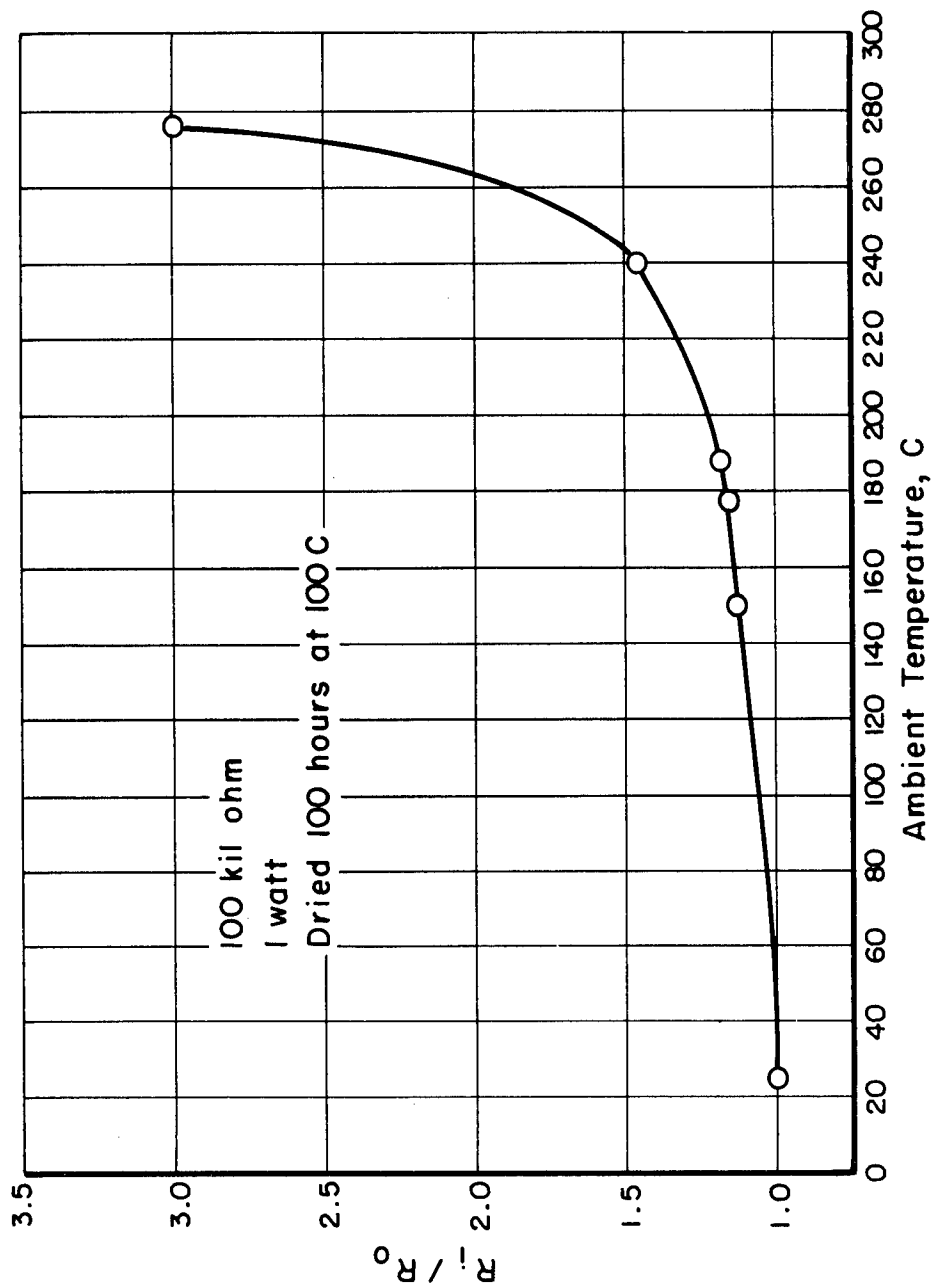


FIGURE 26. RESISTANCE-TEMPERATURE CHARACTERISTIC FOR "A"
RESISTORS, NO LOAD

A-7134

If rise time were critical, it is obvious that specific limits would have to be set in a rating procedure to be used by different persons with different equipment.

To determine how critical rise time is in the measured life of composition resistors, the following tests were made.

This could be done by heating a group of resistors rapidly to some temperature and comparing the results obtained with those obtained by heating slowly a group of resistors from the same batch to the same temperature.

Tests were planned at three equally spaced temperatures on both wet and dry resistors. If our choices of the three temperatures turned out to be good, our results should give: (1) the approximate temperature where rise time does become critical, and (2) the importance of moisture content of the resistor in controlling rise time to temperature.

We planned these tests to include the resistors of three manufacturers.

Experimental Conditions and Results

Only two of the three proposed tests were completed.⁽¹⁾ The tests completed were at about 226 C and 254 C. The resistors had been predried for 100 hours at 100 C.

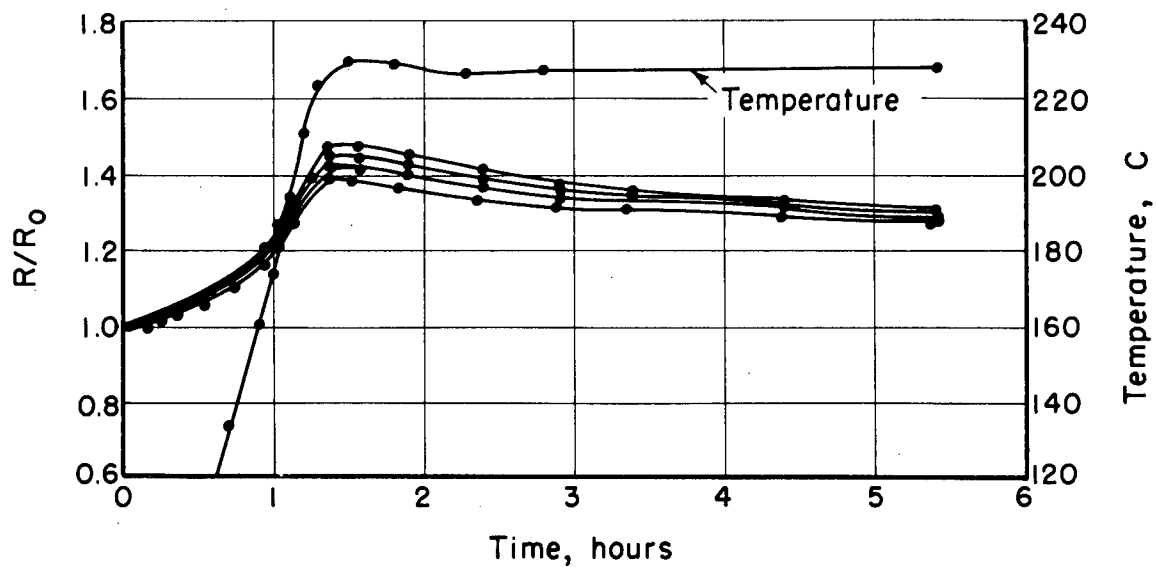
The equipment used for the tests has been described earlier.

Twenty-four resistors were measured in each test (8 from each of three manufacturers). The resistors were mounted on two circular jigs similar to the one shown in Figure 7, page 27, of the Thirteenth Interim Engineering Report. Six Alumel-Chromel thermocouples were placed close to six resistors at different positions on the jigs. The temperature of each resistor was estimated.

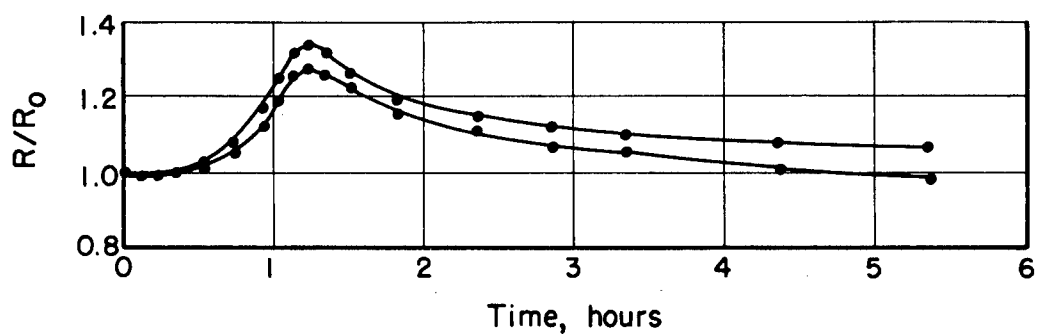
Unfortunately, the temperature distribution in the oven was rather uneven. For example, in the "254 C" test, one resistor was found to be at 268 C. Such a resistor was not considered in the analysis, as a temperature range of 5 C was arbitrarily chosen and all resistors outside this range were not considered.

Typical original data for the tests on dried resistors at 226 C are given in Figures 27 and 28. The rise time was long in Figure 27 (about 1.4 hours). The rise time was short in Figure 28 (about 0.3 hour). The temperature of one resistor is shown in each figure.

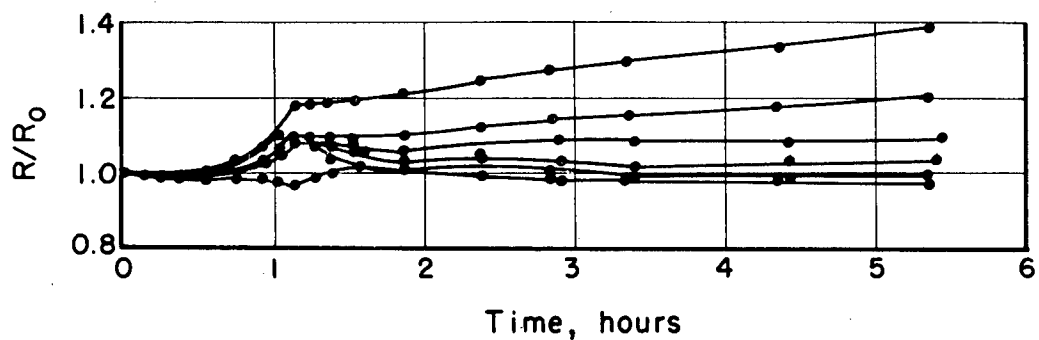
(1) All laboratory tests were stopped on September 30, 1952, at the request of the Air Force.



a. "A" Resistors



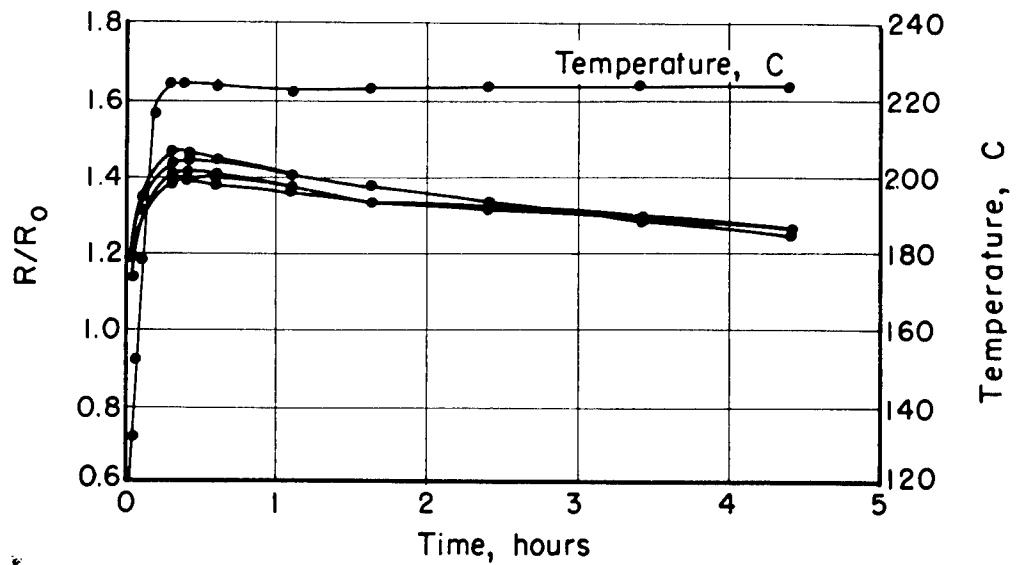
b. "B" Resistors



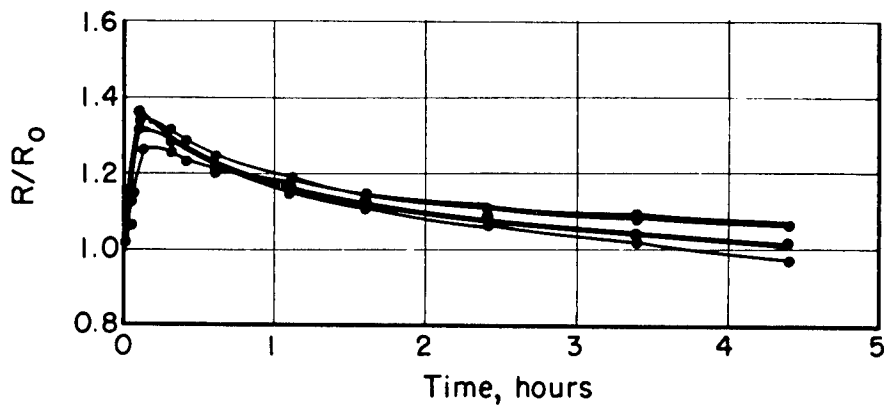
c. "C" Resistors

FIGURE 27. SLOW RISE TEST TO 226 C

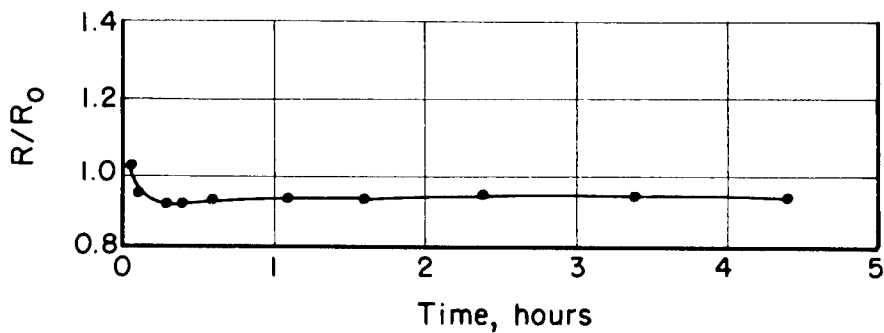
A-7135



a. "A" Resistors



b. "B" Resistors



c. "C" Resistor

FIGURE 28. FAST-RISE TEST TO 226 C

A-7136

Typical original data for the tests at 254 C are given in Figures 29 and 30. The rise time was long in Figure 29 (about 1.1 hours). The rise time was short in Figure 30 (about 0.3 hour).

The customary coordinates used in reporting our resistor work have been used in Figures 27 through 30. The ordinate, R/R_0 , is the ratio of measured resistance at temperature to the original resistance at room temperature. The abscissa, t , is the time (in hours) measured from the time of insertion in the temperature chamber.

Analysis of Results

Two parameters of the basic resistance-versus-time characteristic were used to compare slow rise with fast rise. Other parameters probably could be chosen to show the resistor behavior, but the two chosen are probably most informative in determining the effects of different rise times. The parameters are: (1) initial hot-resistance ratio, i.e., the ratio of resistance when temperature is first reached to the original resistance at room temperature, and (2) per cent change of resistance from the initial hot resistance in a specified time interval.

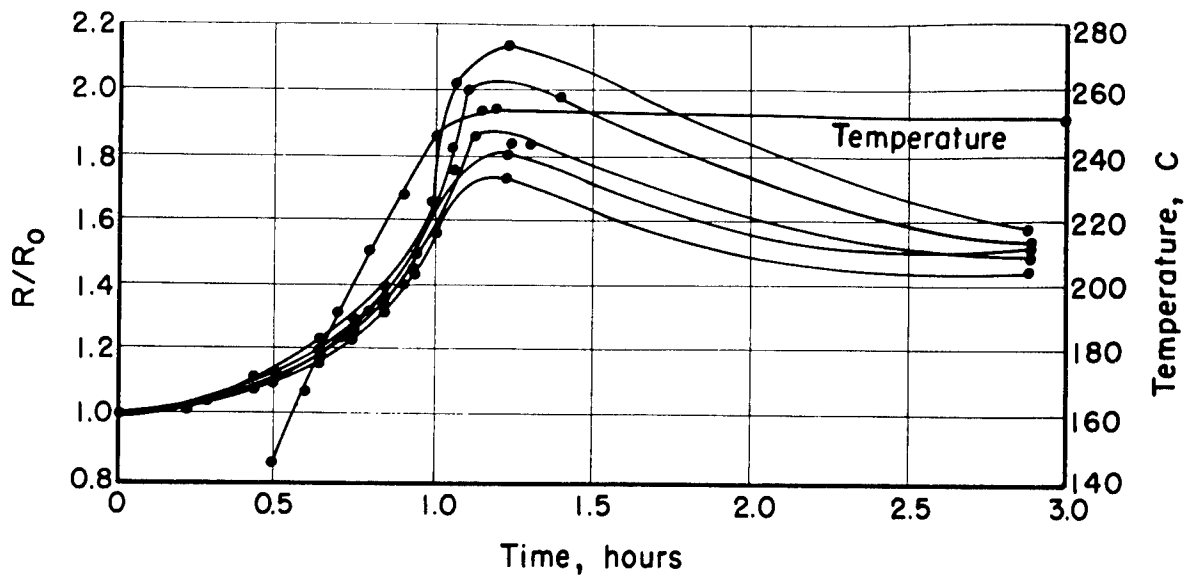
Two statistics were calculated for each of these two parameters in order to compare the results. These statistics are mean (or average) value and variance (or the square of standard deviation). We have commented earlier on the importance of having a statistically sound measure of variability in small-sample testing.

The results of the analysis are summarized in Table 4 for the 226 C test and in Table 5 for the 254 C test. The "comparison" columns in these tables give "significance levels" determined by the method given by Brownlee (pages 24, 34, and 36). A 0.05 level means (approximately) that there is such a decided difference in the values obtained (for the slow and fast rise times) that only five times out of one hundred will this much difference occur purely by chance.⁽¹⁾ Thus, a low (numerically) significance level corresponds to a marked difference.

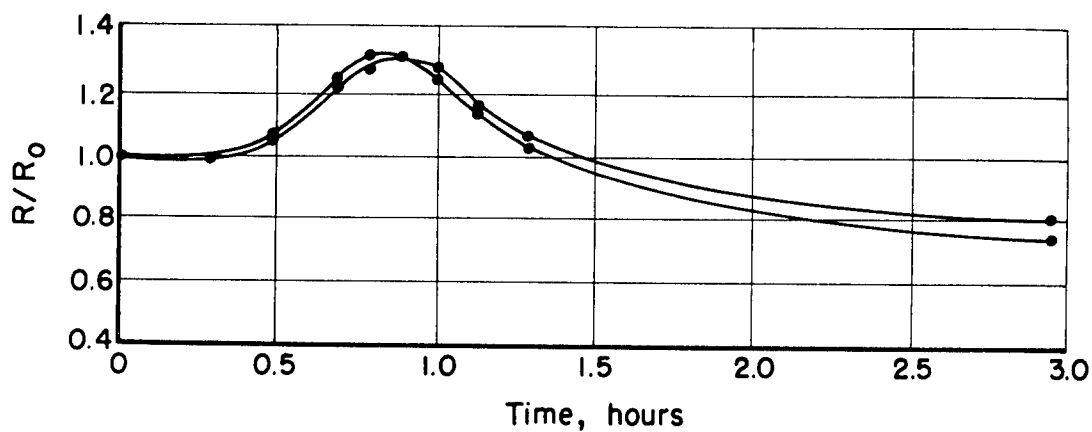
Table 4 shows that the rise time to 226 C has little effect on the resistor behavior for "B" and "C" resistors. "A" resistors appear to have a significantly larger initial hot resistance for the slow rise time.

Table 5 shows little difference for "B" resistors at 254 C. "C" resistors have a significantly larger initial test resistance and a larger

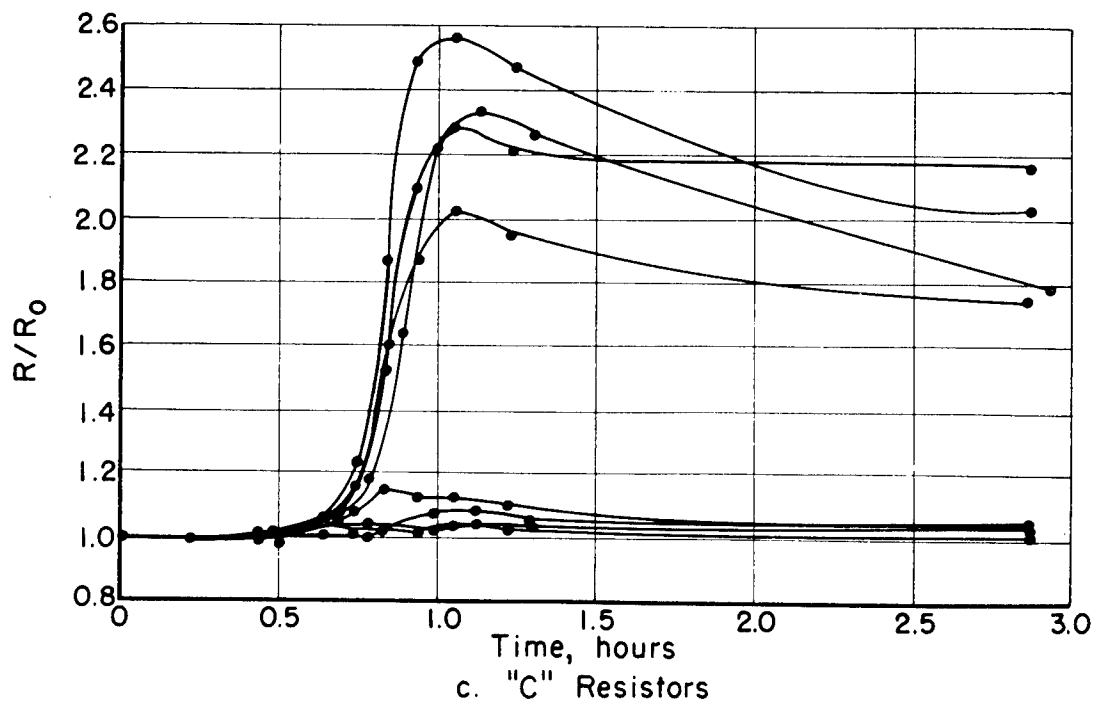
(1) This statement is not entirely accurate in a statistical sense but gives an idea of what is involved.



a. "A" Resistors



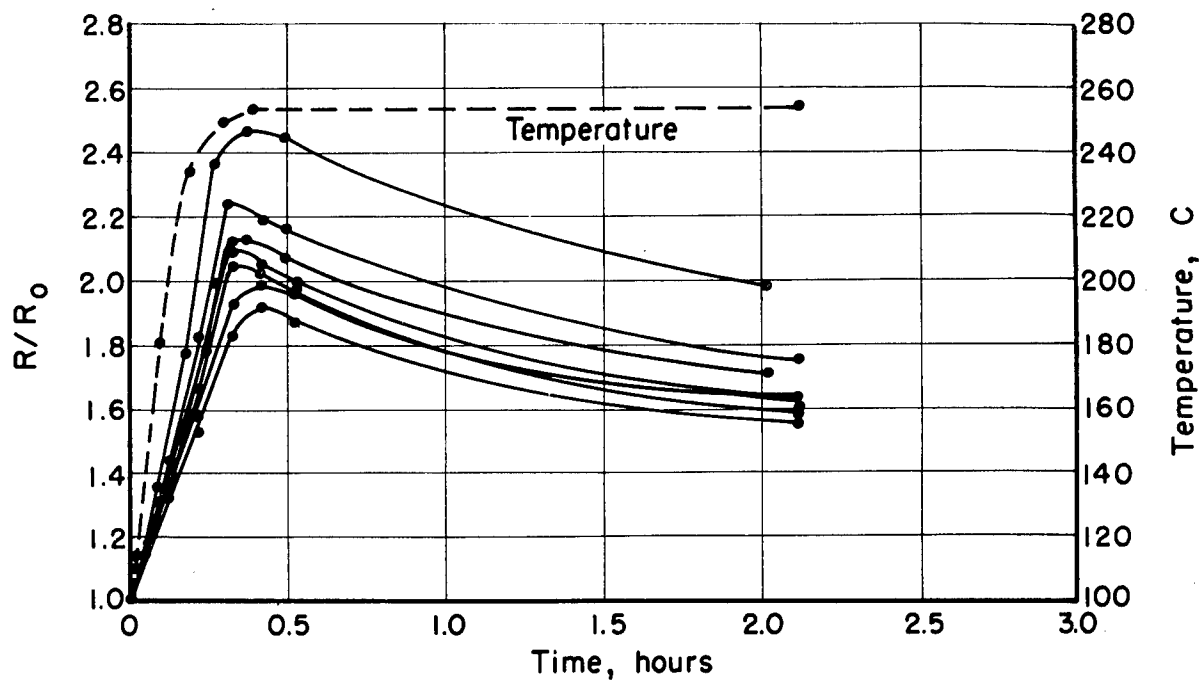
b. "B" Resistors



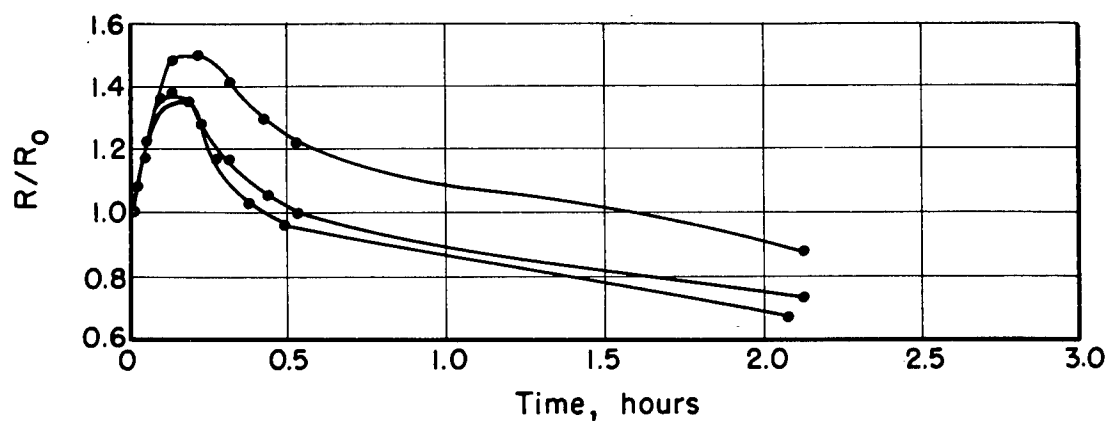
c. "C" Resistors

FIGURE 29. SLOW-RISE TEST TO 254 C

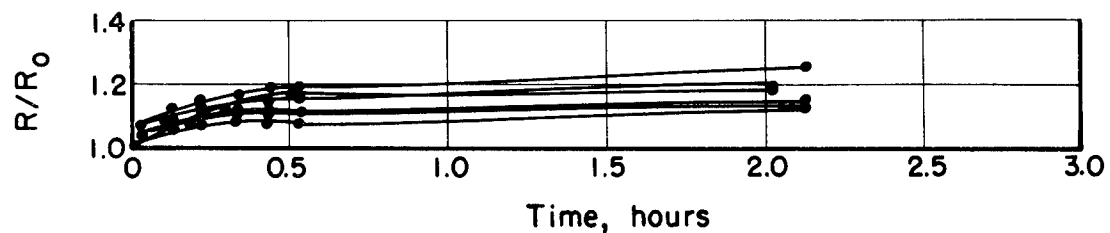
A-7137



a. "A" Resistors



b. "B" Resistors



c. "C" Resistors

FIGURE 30. FAST-RISE TEST TO 254 C

A-7138

TABLE 4. RISE-TIME TESTS AT 226 C

Parameter	Statistic	Test						Comparison of Tests (Significance Level)		
		Slow Rise			Fast Rise					
		Manufacturer			Manufacturer					
		A	B	C	A	B	C	A	B	C
Initial hot resistance ratio	Mean	1.64	1.28	1.07	1.41	1.29	0.92	0.001	ND*	--
	Variance	1.47	2.11	3.92	1.09	0.54	--	ND	0.20	--
Per cent resistance change in 2 hours	Mean	-7.1	-15.9	1.02	-6.7	-13.5	16.5	ND	ND	--
	Variance	1.3	0.005	38.1	2.8	5.8	--	ND	0.05	--
Per cent resistance change in 4 hours	Mean	-10.8	-19.6	2.7	-10.6	-18.1	15.6	ND	ND	--
	Variance	1.9	2.1	14.1	5.3	14.0	--	ND	0.20	--

*ND = No (significant) difference.

TABLE 5. RISE-TIME TESTS AT 254 C

Parameter	Statistic	Test						Comparison of Tests (Significance Level)		
		Slow Rise			Fast Rise			Manufacturer		
		Manufacturer			Manufacturer			Manufacturer		
		A	B	C	A	B	C	A	B	C
Initial hot resistance ratio	Mean	1.89	1.14	1.69	2.07	1.18	1.12	0.02	ND*	0.10
	Variance	0.023	0.0003	0.48	0.022	0.01	0.0015	ND	0.20	0.001
Per cent resistance change in 1.81 hours	Mean	-19.8	-32.3	8.6	-21.9	-37.4	4.1	ND	0.10	0.01
	Variance	14.4	10.7	72.8	1.7	5.1	7.6	0.20	0.20	0.05

*ND = No (significant) difference.

percentage change (corresponding to a shorter life) for the slow rise time. The variability is considerably lower for "C" resistors in the fast rise time. "A" resistors show a significantly larger initial test resistance for the fast rise time. (This result contradicts the result for "A" resistors at 226 C.)

Conclusions

There are statistically significant differences in the data for slow and fast rise times at both temperatures. The differences are more pronounced at 250 C than at 220 C. (The variance, in particular, is greater at 250 C.)

On the basis of variability, fast rise is preferable for "A" and "C" resistors, but slow rise is preferable for "B" resistors. Thus, no firm conclusion on the most desirable rise time can be drawn without further testing. It has been shown, however, that rise time should be controlled, especially at the higher temperatures, in order to avoid incorrect ratings.

Batch Tests

Purpose

We indicated on page 8 the need for sampling at successive intervals. It is known that the life characteristics of resistors may change from time to time. In order to keep the life rating information in ECIC up to date, we must determine how often rating tests should be performed. "How often" will depend, of course, directly on the variability encountered from one batch to the next.

The tests described in this section are two of an unfinished series designed to determine batch variability for two types of composition resistor. We also planned, originally, to determine the effect of controlled moisture content on batch variability.

Experimental Conditions and Results

The equipment used for two tests on "A" and "C" resistors has been described on page 43. The resistors were predried for 100 hours at 100 C before testing.

Twenty-four "C" resistors (12 from each of two batches received 2 months apart) were heated in an oven to about 230 C and measured as a

function of time. Results are shown graphically in Figure 31. All curves in Figure 31 are for the same test, but have been separated for clarity.

The temperatures of five resistors in different locations were measured with Chromel-Alumel thermocouples. The temperature distribution was rather uneven in this test; a maximum difference of 28 C was noted when the resistors initially reached oven temperature. This difference later decreased to a maximum of 11 C. The temperature of one resistor (near the average temperature) is shown in the top set of curves of Figure 31.

Twenty-four "A" resistors (12 from each of two batches received 5-1/2 months apart) were heated to about 195 C. The results are shown graphically in Figure 32. The temperature spread between resistors reached a maximum of only 5 C for this test.

Analysis of Results

Three basically different parameters of the resistance-versus-time characteristic were used to compare the first batch with the second batch. These are: (1) initial hot-resistance ratio, i. e., the ratio of resistance when temperature is first reached to the original resistance at room temperature, (2) per cent change of resistance from the initial hot resistance in an 8-hour period, and (3) per cent change of resistance from the original resistance at room temperature to the final resistance at room temperature after the 8-hour (plus heating-up time) period.

We found two statistics for each of these three parameters: mean (or average) value and variance (or the square of standard deviation). The results of analysis are summarized in Table 6 for the "C"-resistor test and in Table 7 for the "A"-resistor test. The meaning of the entries in the columns labeled "Comparison" in these tables has been given on page 77. Note that "Resistance ratio, original room-temperature value to final room-temperature value" is tabulated in Table 7. This is effectively the same as "per cent resistance change from original room-temperature value to final room-temperature value" in Table 6.

Table 6 indicates very little significant difference in either mean values or variances for the "C" resistors received two months apart. Table 7 indicates there is some difference in the batches of "A" resistors received 5-1/2 months apart. The most significant difference is reflected in the parameter "per cent resistance change from original room-temperature value to final room-temperature value".

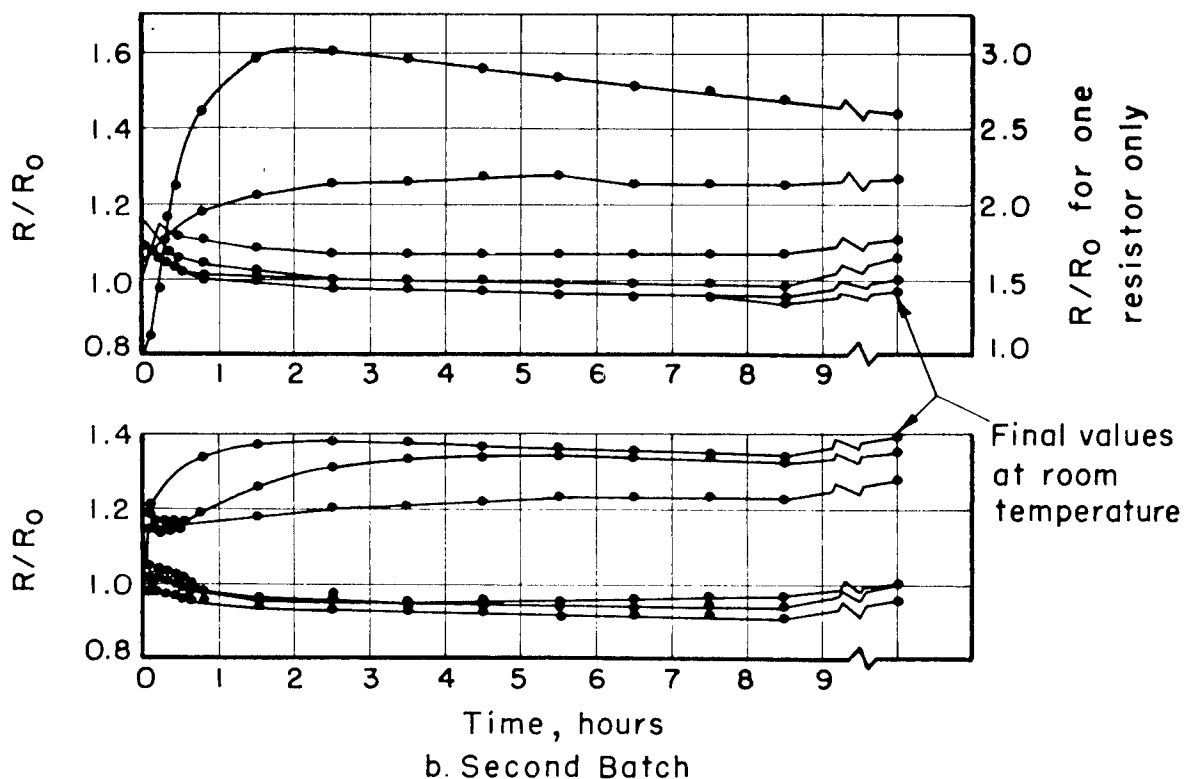
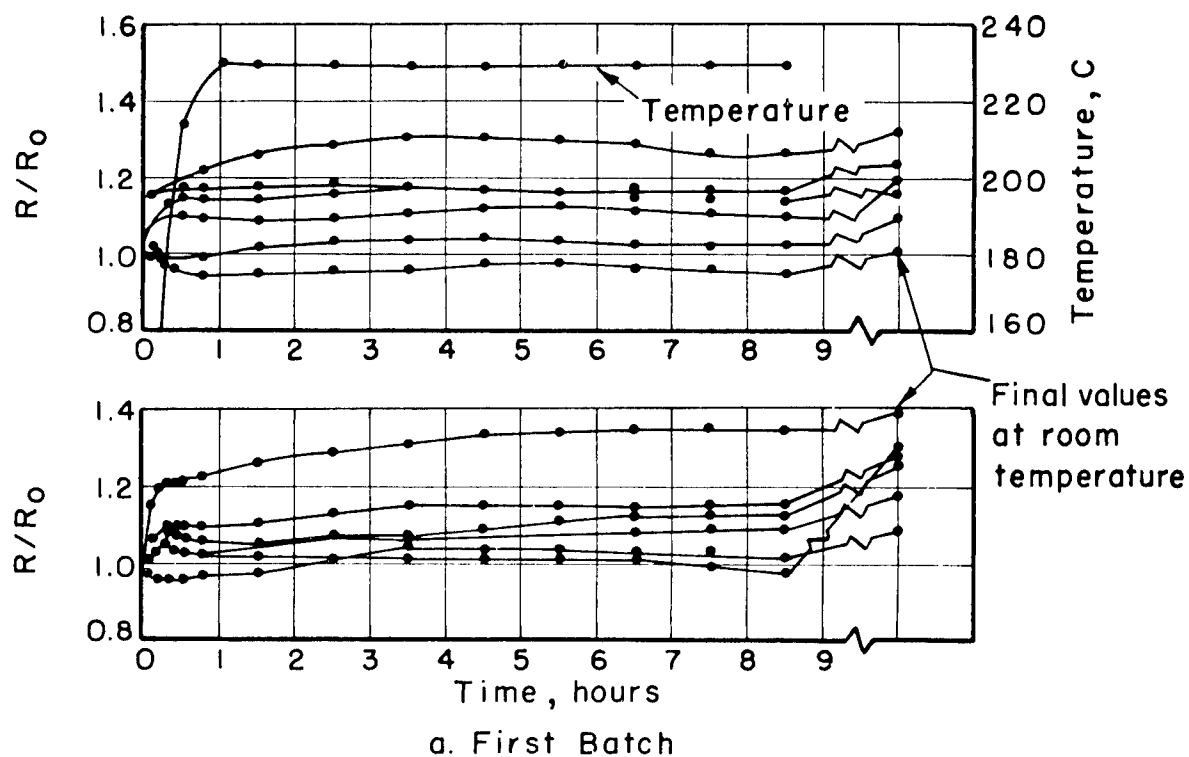
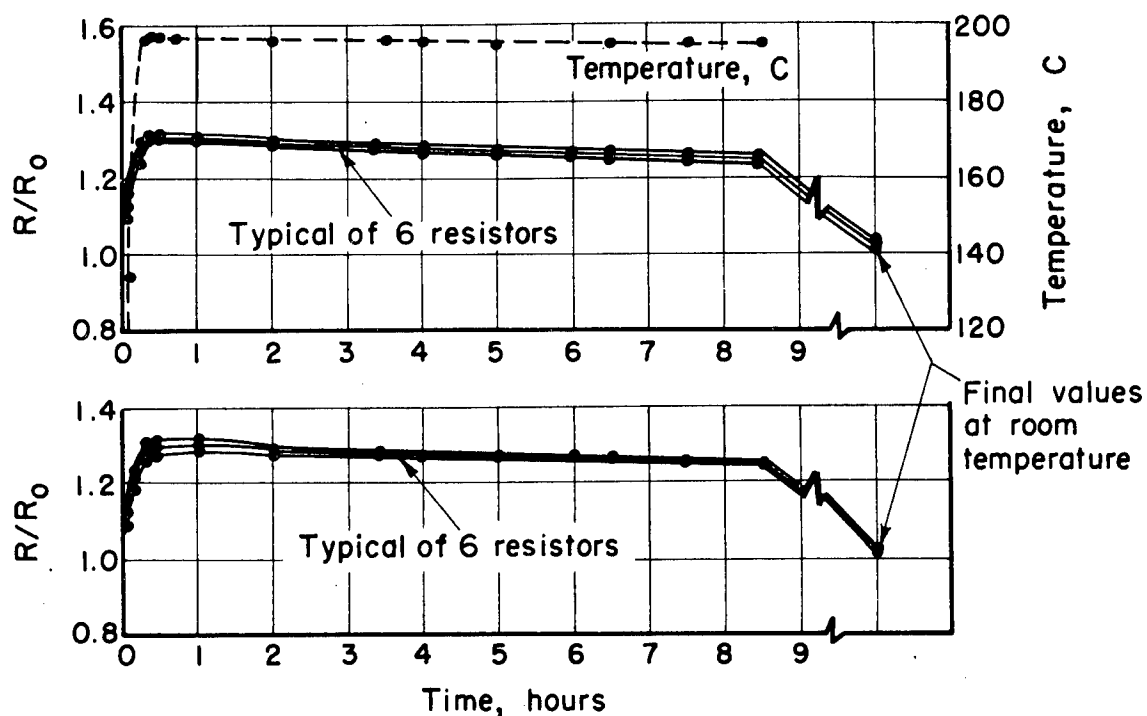
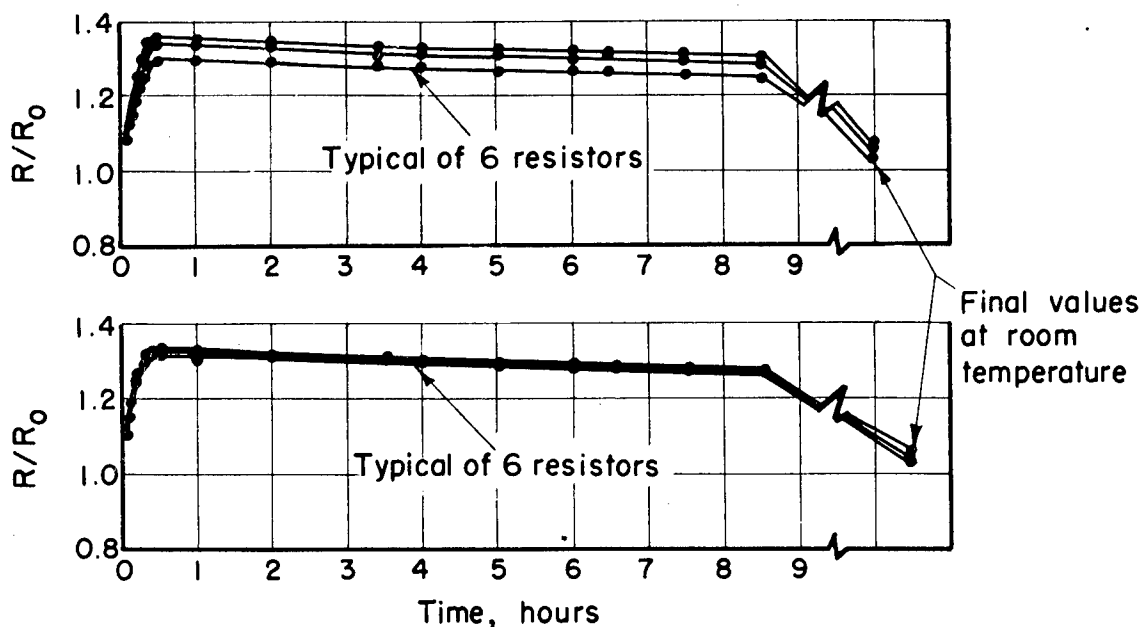


FIGURE 31. LIFE TESTS FOR "C" RESISTORS RECEIVED TWO MONTHS APART

A-7139



a. First Batch



b. Second Batch

FIGURE 32. LIFE TEST FOR "A" RESISTORS RECEIVED
5½ MONTHS APART

A-7140

TABLE 6. BATCH TEST FOR "C" RESISTORS
RECEIVED 2 MONTHS APART

Parameter	Statistic	Batch		Comparison
		First	Second	
Initial hot resistance ratio	Mean	1.086	1.084	ND*
	Variance	0.0085	0.0094	ND
Per cent resistance change in 8 hours	Mean	0.272	0.069	ND
	Variance	0.236	0.708	0.05
Per cent resistance change from original room- temperature value to final room-temperature value	Mean	18.38	26.85	ND
	Variance	37.7	1917.6	0.001

*ND = No (significant) difference.

TABLE 7. BATCH TEST FOR "A" RESISTORS
RECEIVED 5-1/2 MONTHS APART

Parameter	Statistic	Batch		Comparison
		First	Second	
Initial hot resistance ratio	Mean	1.303	1.315	0.10
	Variance	0.00018	0.00031	0.20
Per cent resistance change in 8 hours	Mean	4.02	3.59	0.05
	Variance	0.22	0.16	ND*
Resistance ratio, original room-temperature value to final room-temperature value	Mean	0.93	2.90	0.001
	Variance	0.29	1.51	0.05

*ND = No (significant) difference.

Conclusions

"A" resistors received 5-1/2 months apart differ in their short-life characteristics, and "C" resistors received 2 months apart do not differ appreciably. Thus, it is necessary to obtain samples at periodic intervals before assigning life ratings.

Further testing is essential to determine the optimum intervals for sampling composition resistors to test the life characteristic.

Surface-Temperature - Load Tests

Figure 33 illustrates the type of data obtained by following the detailed test procedure given in Paragraph E-2a, page 29 (the temperature-altitude tests). The resistance-measuring circuit of Figure 5 was used. The curves show an interesting experimental limitation in loading "A" resistors.

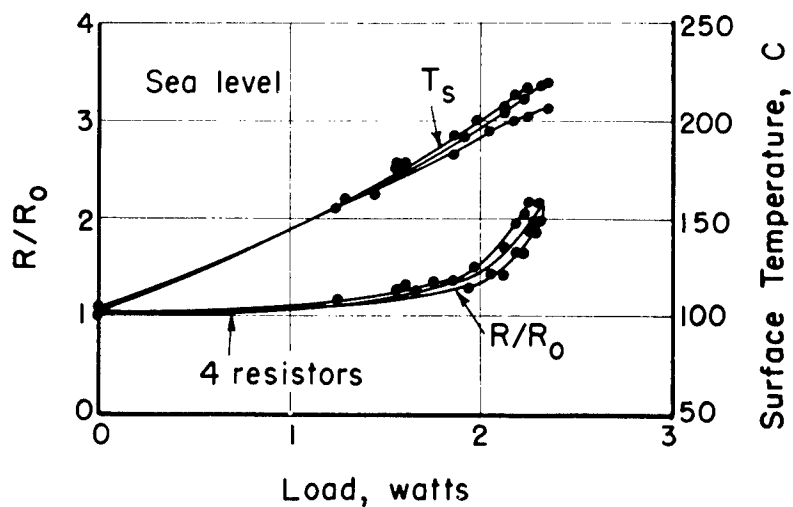
Recall that the experimental procedure is to apply voltage across the resistors, then measure surface temperature and resistance after "resistor stability" is obtained, but before significant deterioration occurs. For Figure 33a, this results in rather straight T_s and R/R_0 curves up to about 1.6 watts. Then a load limit is approached at which the resistance curve bends upward rapidly. Further increases in voltage are balanced by the increase in resistance (load = (voltage)²/resistance). At the higher ambient temperature (Figure 33b), the load limit occurs earlier.

Conclusions

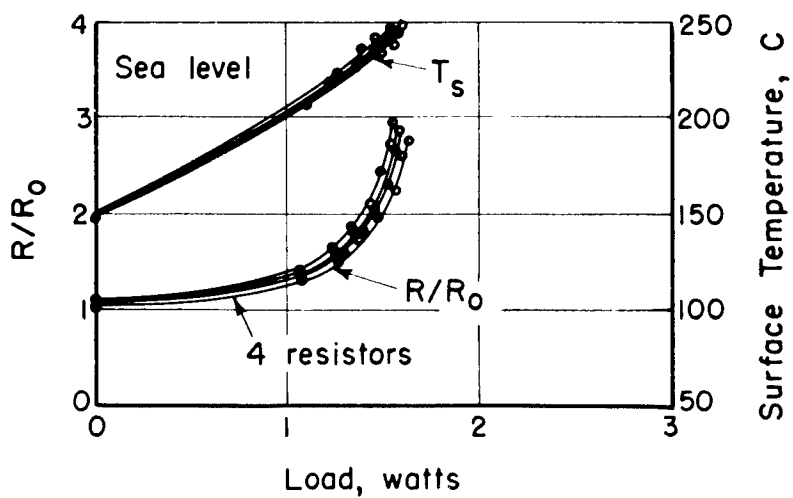
The procedure for load and surface-temperature tests specified in the detailed rating procedure given earlier appears satisfactory, at least until a background of experimental results is obtained which may indicate desirable changes. The nature of the resistance change (i. e., the upper load limit) requires that some arbitrary "stopping place" be specified in the procedure. The detailed procedure specifies that tests continue until the surface temperature of one or more of the resistors is equal to or greater than 280 C (Paragraph E-2a (2)).

CONCLUDING REMARKS

The work described in this report has resulted in the first detailed procedure for short-term-life rating of composition resistors. Many of the tests



a. Ambient Temperature = 100 C



b. Ambient Temperature = 150 C

FIGURE 33. SURFACE-TEMPERATURE—LOAD TESTS OF "A" RESISTORS

A-7141

specified in the procedure are basically new for a very good reason: no test specifications for resistors now exist which apply directly to the short-term life-rating problem.

It appears that this work demonstrates the desirability for adopting an approach to life rating of electronic components which includes experimental verification of proposed test procedures.

The procedure given here has not been thoroughly verified experimentally. Testing experience probably will show that the procedure should be modified and perhaps expanded in many places. However, by making intelligent approximations and applying proper safety factors, it is expected that the rating information which can be supplied by tests in this procedure will go far toward determining the reliability of composition resistors in short-life high-temperature applications.

Original data for the work described in this report are recorded in Battelle Memorial Institute Laboratory Record Books Numbers 5788, 5821, 6057, 6301, 6642, 6717, 7101, 7102, 7210, 7211, 7212, and 8283.

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